(54) Title: METHOD FOR CO-CHANNEL INTERFERENCE CANCELATION IN A MULTICARRIER COMMUNICATION SYSTEM

(57) Abstract: The present invention relates to an interferance signal cancel ing method, a receiver using the same and a digital multi-carrier communication system comprising such a receiver. A main aspect of the present invention is to apply an interference cancellation scheme to a digital multi-carrier communication system. By using a digital multi-carrier communication system, the effect of the inter-symbol interference is avoided. As a result the receiver (8) comprises a plurality (L) of interference cancellers (17_1-17_L) each of which is assocaiated to a respective one of sub-carrier signals for canceling only co-channel interference.

METHOD FOR CO-CHANNEL INTERFERENCE CANCELATION IN A MULTICARRIER COMMUNICATION SYSTEM

The present invention relates to an interference signal
5   canceling method, a receiver using the same and a digital
multi-carrier communication system comprising such a
receiver. More particularly, it relates to an interference
signal canceling method which compensates the transmission
performance degradation due to co-channel or similar
10   interference signals from other adjacent cells in digital
mobile radio communication or other adjacent transmitter in
digital wireless communication or in digital broadcasting
system and a receiver and a communication system using such
an interference signal canceling method.

15   There have already been proposed several types of
receivers which employ replica generators for interference
canceling. They generate replicas by using transmission
symbol candidates both for desired and interference signals,
and transmission channel parameters corresponding to these
20   two signals. Then, they subtract these replicas from a
received signal to obtain an error signal. They multiply the
square of the error signal by -1 and use the resulting signal
as a metric for a maximum likelihood sequence estimation
(MLSE) both for desired and inter-channel interference
25   signals under inter-symbol interference condition.

     For example, W. Van Etten has proposed a receiver using
the Viterbi algorithm as a maximum likelihood sequence
estimator (W. Van Etten, "Maximum Likelihood Receiver for
Multiple Channel Transmission System," IEEE Trans. on Comm.

February 1976). However, this receiver is based on the assumption that the channel impulse response values are preknown. A receiver that estimates channel parameters and employs a maximum likelihood sequence estimation has been

5 proposed by Howard E. Nicols, Arithur A. Giordano and John G. Proakis (H. E. Nichols, A. A. Giordano, and J. G. Proakis, "MLD and MSE algorithm for adaptive detection of digital signals in the presence of interchannel interference," IEEE Trans. on Information Theory, September 1977). According to

10 their proposal, the channel parameters are estimated and updated by an adaptation algorithm by using an estimated symbol value which is output from the maximum likelihood sequence estimator with a decision delay of several symbol duration. This receiver operates well when the radio channel

15 has relatively slow time-variations. In the mobile radio channel, however, since the amplitudes and phases of desired and interference signals vary very rapidly, the estimated channel parameters with the time delay of several symbol duration represent no longer the current channel impulse

20 response. Hence, the transmission performance is seriously degraded.

To improve the transmission performance of a receiver based on the maximum likelihood sequence estimation scheme, A.P. Clark, J. D. Harvey and J. P. Driscoll have proposed a

25 Near-Maximum-Likelihood detection scheme as a solution to the poor channel parameter estimation due to the fixed estimation delay which poses a serious problem in the adaptive maximum likelihood sequence estimation receiver (A. P. Clark, J. D. Harvey and J. P. Driscoll, "Near-Maximum-Likelihood detection

30 processes for distorted digital signals, "Radio & Electronics Engineer, Vol. 48, No. 6, pp.301-309, June 1978).

Moreover, A. P. Clark has proposed an FDM (Frequency Division Multiplexing) system that transmits two signals over the same frequency channel through utilization of the Near-Maximum-Likelihood detection scheme (U.S. Pat. No.4,862,483).

5 In this system, however, the number of the transmission signal sequence candidates (first vector) to be stored in a memory and the number of the sets of transmission channel parameters (vectors) corresponding to the first vector are large. Each first vector is extended into a second vector by

10 adding a further component representing a respective combination of data symbols that could be received at the sample instant. New signal sequence candidates (first vectors) are selected among the extended signal sequence candidates (i.e. second vectors) in a highest likelihood

15 order. When the likelihood of the transmission signal sequence candidate (first vector) who has the highest likelihood is extremely higher than that of the other signal sequence candidates (first vectors), the likelihood order of the extended sequence candidates (second vectors) depends

20 dominantly on the likelihood value of the first vector. Hence, there is almost no possibility of other first vectors being selected. This receiver can no longer be considered as a maximum likelihood detector.

H. Yoshino, K. Fukawa and H. Suzuki have proposed, as an

25 interference signal canceling method, a receiver using a transmission parameter estimation scheme suitable for the maximum likelihood sequence estimation which keeps high-speed, precise track of the fast fading or fast changing mobile radio channel (U.S. Pat. No. 5,537,443). An

30 interference canceller of this scheme cancels both inter-symbol interference and co-channel interference, but the number of the states in the Viterbi algorithm increases

exponentially as the maximum excess delay caused by multi-path propagation increases. When the signal delay exceeds the maximum signal delay considered in the Viterbi algorithm, the maximum likelihood sequence estimator does not work, and the

5   transmission performance is seriously degraded.

On the other hand, S. B. Weinstein and P. M. Ebert have proposed a modulation and demodulation scheme to overcome the effect of the inter-symbol interference which is denoted orthogonal frequency division multiplexing (OFDM) and uses

10   the discrete Fourier transform (S. B. Weinstein and P. M. Ebert, "Data transmission by frequency division multiplexing using the discrete Fourier transform," IEEE Trans. on Comm., October 1971). A receiver of this scheme does not cancel co-channel interference, and hence possesses the drawback that

15   it does not operate in a high co-channel interference environment.

The present invention applies the above mentioned transmission channel parameter estimation scheme and co-channel interference cancellation scheme to an above

20   mentioned frequency division multiplexing system. By using frequency division multiplexing system, the effect of the inter-symbol interference is avoided. By exploiting the different channel characteristics, say, the difference in amplitudes and phases between desired and interference

25   signals, the transmitted symbol sequences can be simultaneously estimated both for the desired and the interference signals).

A description will be given first, with reference to FIG.1A and FIG.1B, of a conventional scheme of the orthogonal

30   frequency division multiplexing (OFDM) data transmission that has the above-said feature of avoiding the intersymbol interference. Fig. 1A shows the transmitter scheme for an

OFDM data transmission system. This transmitter is made up
of: a serial to parallel (S/P) converter 1 which converts
serial data stream to a set of L parallel data streams;
parallel baseband modulators 2 to which the data in each sub-

5   channel are fed; an inverse discrete Fourier transform (IDFT)
device 3, whose outputs correspond to L channel transmitted
signals with carrier frequencies f_0, f_1, ..., f_{L-1}, where the
frequency difference between adjacent channels is Df and the
overall bandwidth W of the L modulated carriers is $L\ Df$; a

10   cyclic extension device 4 which adds a cyclic prefix (guard
interval) in order to avoid the effect caused by inter-block
interference; a parallel to serial converter (P/S) 5 to
output time domain signal; a digital-to-analog (D/A)
converter 6 which converts digital signal to an analog

15   waveform; and a low pass filter 7 which limits the frequency
spectrum.

Fig. 1B shows the receiver scheme for an OFDM data
transmission system. This receiver is made up of a low pass
filter 10 which band-limits the received signal; an analog-

20   to-digital (A/D) converter 11 which converts the analog
received signal to digital form; a serial-to-parallel (S/P)
converter 12 which converts the serial received signal to L
parallel data streams; a remove cyclic extension device 13
which removes the cyclic prefix in order to remove the effect

25   of time domain inter-symbol interference; a discrete Fourier
transform (DFT) device 14 whose output are L sub-carrier
channels; L baseband demodulators 15 which demodulate
baseband received symbols to digital data bits; and a
parallel-to-serial (P/S) converter 16 which recombines

30   digital data bits to a serial data bit sequence. An advantage
of the OFDM data transmission system is that OFDM reduces the
effects of intersymbol interference (ISI) by lowering the

symbol rate for each sub-carrier. Particularly, for the
application of high bit rate digital signal transmission,
OFDM also can eliminate the effect of ISI by adding a cyclic
prefix, the length of which is set to be greater than the

5   maximum excess delay of the transmission channel. When the
received signal contains an interference signal from another
transmitter, the interference signal still remains on each of
the sub-channels so that the transmission performance is
seriously degraded. In a cellular mobile communication system

10   in which each cell may sometimes receive a co-channel
interference signal from an adjacent cell, or in wireless
local or wide area network in which the same frequency
channel is reused (e.g. space division multiple access (SDMA)
systems), there is a strong demand for canceling the

15   influence of the interference. In a digital broadcasting
system, such as digital audio broadcasting (DAB) or digital
video broadcasting (DVB), the receiver at the fringe of a
broadcasting service area suffers a co-channel interference
from the transmitter in an adjacent broadcasting service area

20   if in both service areas the same frequency channels are
used. Thus, there is also a strong demand for canceling the
interference signal.

       An object of the present invention is to provide a
multi-carrier receiver, e. g. an OFDM receiver, a digital

25   signal transmission multi-carrier communication system and a
method for canceling co-channel interference in a multi-
carrier signal which use a less complex and thus a cheaper
interference cancellation scheme than the prior art according
to US-PS-5 537 443.

30   A main aspect of the present invention is to apply the
above mentioned interference cancellation scheme to a digital
multi-carrier communication system. By using a digital multi-

carrier communication system, the effect of the inter-symbol interference is avoided. As a result an interference canceller which only cancels co-channel interference is used for each sub-carrier signal. By exploiting the different

5   channel characteristics, say, the difference in amplitudes and phases between desired and interference signals, the transmitted symbol sequences can be simultaneously estimated both for the desired and the interference signals.

The above mentioned technical problem is solved by the

10   features of claim 1, claim 18 and claim 19, respectively.

Further preferred embodiments are set forth in the dependent claims.

The receiver comprises at least one receiving branch, wherein each receiving branch comprises demodulating means

15   for converting a received serial multi-carrier signal including at least one desired and interference signal into a plurality of sub-carrier signals, and a plurality of interference cancellers each of which is associated to a respective one of said sub-carrier signals for canceling co-

20   channel interference.

In a preferred embodiment each interference canceller comprises a transmitted symbol estimation part connected to a metric generator for applying a set of symbol candidates both for the at least desired and interference signals to the

25   metric generator and for receiving metric values generated by the metric generator by using a received sub-carrier signal and said set of symbol candidates, wherein said transmitted symbol estimation part (40) determines the most likely set of symbol candidates by using the metric values.

30   In a preferred embodiment the metric generator comprises a channel parameter estimation part for estimating signal transmission channel parameters both of the at least one

desired and interference signals by using the set of the
desired and the interference signal symbol candidates
provided by said transmitted symbol estimation part and an
estimation error signal provided by an error estimation part,
5   a replica generator for generating a replica signal from both
of the desired and the interference signals by using the set
of the desired and the interference signal symbol candidates
and the desired and the interference signal channel
parameters provided by said channel parameter estimation
10   part, wherein the error estimation part generates the
estimation error signal by using said received sub-carrier
signal and the replica signal and a metric calculator
connected to the transmitted symbol estimation part for
generating metric values from the estimation error signal.

15   The replica generator of each metric generator may
comprise a desired signal estimation part for generating the
replica of the desired signal by using the channel parameter
of the desired signal and a desired signal symbol candidate
provided by the transmitted symbol estimation part, at least
20   one interference signal estimation part each for generating a
replica of a respective interference signal by using the
interference signal transmission channel parameters and
interference signal symbol candidates provided by the
transmitted symbol estimation part, a replica combining adder
25   for combining the generated replicas of the desired and
interference signals and outputting the combined replica to
the error estimation part.

The transmitted symbol estimation part may comprise a
first modulation signal generator for generating desired
30   signal complex modulation symbols, at least one second
modulation signal generator for generating interference
signal complex modulation symbols. The replica generator of

each metric generator comprises a first complex multiplier
for multiplying the output signal of the first modulation
signal generator with the desired signal transmission channel
parameter generated by the channel parameter estimation part,
at least one second complex multiplier for multiplying the
output signal of the respective second modulation signal
generator with the respective interference signal
transmission channel parameter generated by the channel
parameter estimation part, a replica combining adder
connected to said first and at least one second multiplier
for summing the desired and interference signal replicas.

The transmitted symbol estimation part may further
comprise a first training sequence memory unit for storing a
desired signal training bit sequence and for generating a set
of training bits, at least one second training sequence
memory unit each of which stores an interference signal
training bit sequence and each of which generates a set of
training bits of a corresponding interference signal, a
maximum likelihood estimator, a first switch for connecting
the first training sequence memory unit during a training
period and a respective output of the maximum likelihood
estimator during a tracking period to the first modulation
signal generator, at least a second switch for connecting the
respective second training sequence memory unit during a
training period and a respective output of the maximum
likelihood estimator during a tracking period to the
respective second modulation signal generator.

In a preferred embodiment the channel parameter
estimation part comprises a channel estimator having inputs
connected to the first and second modulation signal
generators and to the error estimation part and outputs
connected to the first and second complex multiplier

estimating and/or updating said desired and interference transmission channel parameters by using an adaptation algorithm.

In an alternative embodiment the channel parameter estimation part comprises a channel estimator having inputs connected to the first and second modulation signal generators and to a switch and outputs connected to the first and second complex multiplier, wherein the switch controlable supplies the received sub-carrier signal which is also applied to the error estimation part or the error signal generated by the error estimation part to the channel estimator.

The metric calculator may comprise an absolute-square circuit for calculating an absolute-squared value of the applied error signal.

The error estimation part may comprise a subtractor for subtracting said replica signal provided by the replica combining adder from said respectively received sub-carrier signal to generate said estimation error signal.

In an alternative embodiment the receiver is a multi-branch diversity receiver comprising a plurality of interference cancellers, each of which comprises a transmitted symbol estimation part connected to a number of metric generators for applying a set of symbol candidates both for the desired and interference signals to the metric generators, wherein the number of metric generators corresponds to the number of receiving branches, wherein each metric generator generates metric values by using a respective received sub-carrier signal of a different diversity branch and said set of symbol candidates, and a diversity combiner connected to the metric generators for combining the metric values received from the metric

generators, wherein said transmitted symbol estimation part determines the most likely set of symbol candidates both for the desired and interference signals to be transmitted by using the metric values received from the diversity combiner.

5   In an alternative embodiment the diversity combiner comprises a branch combining weight controller which receives a respective received sub-carrier signal on each receiving branch for computing combining weight-coefficients and outputting said weight-coefficients, a plurality of

10   multipliers each connected to a respective metric generator, a diversity combining adder having inputs connected to the multipliers and an output connected to the transmitted symbol estimation part

In particular, the receiver subtracts an estimated

15   desired received sub-carrier signal and an estimated interference sub-carrier signal from a received sub-carrier signal and gets an error signal. The receiver determines transmitted signal symbol sequence both of desired and the interference signal with the error signal by using a maximum

20   likelihood estimation device. The error signal can also be used for channel parameter estimation by using adaptation algorithms. In this receiver, both the desired and multiple of interference signals are estimated so as to minimize the estimation error signal. Hence, the receiver provides an

25   excellent signal transmission performance even under a strong interference signal co-existence condition. This receiver can easily be extended to a multi-user receiver by outputting the estimated symbol sequences not only of the desired signal but also of the interference signals.

30   According to the present invention, a desired signal candidate which corresponds to one of the possible desired signal symbols to be transmitted and the interference signal

candidates which correspond to one of the possible signal
symbols of the interference signals to be transmitted from
other stations are generated in a maximum likelihood
estimator. These candidates are fed to a part to generate
5   estimated desired and interference signals (called replica
signals thereafter). The desired and interference replica
signals are subtracted in an error estimation part from the
received signal to compute estimation error signal. The error
signals are calculated for every set of desired and
10   interference candidates. The maximum likelihood estimator
selects the set of the desired signal and interference
signals which has the highest likelihood metric (least
estimation error). A channel parameter estimation part
determines or updates the transmission channel parameters by
15   using an adaptation algorithm so as to minimize the
estimation error signal.

For the correct set of desired and interference signal
symbol, both the desired signal and the interference signal
components is removed, and hence the major component in the
20   estimation error signal becomes noise and channel estimation
error components. Consequently, the maximum likelihood
estimation on each sub-channel is free from the influence of
the interference signal. Thus, it is possible to provide an
excellent receiving performance unaffected by the
25   interference signal even if the received signal contains
interference signals. According to the present invention, the
desired and interference signals are treated in the same
manner in terms of signal processing. Thus, this invention
can be easily extended to a multi-user detection receiver if
30   both the desired and the interference signal information
sequences are output in the maximum likelihood estimator.

The features of this invention are set forth in the

appended claims. The invention, together with its objects and
the advantages thereof, may be best understood by reference
to the following description taken in conjunction with the
accompanying drawings, in which like references numerals
5   identify like elements in the figures and in which:

FIG. 1A is a block diagram of a conventional transmitter
         using an inverse discrete Fourier transform (IDFT) in
         an OFDM transmission system;

10   FIG. 1B is a block diagram of a conventional receiver using a
         discrete Fourier transform (DFT) in an OFDM
         transmission system;

     FIG. 2A is a block diagram of an OFDM receiver using an
         interference canceller illustrating conceptual

15   construction of the present invention;

     FIG. 2B is a block diagram of a parallel configuration of
         interference cancellers illustrating conceptual
         construction of the present invention;

     FIG. 2C is a block diagram of an interference canceller using

20   a metric generator illustrating conceptual
         construction of the present invention;

     FIG. 3   is a block diagram of an interference canceller
         illustrating a conceptual block of a replica
         generation type of the present invention.

25   FIG. 4   is a block diagram of an interference canceller
         illustrating a replica generation type of the present
         invention.

     FIG. 5A is a block diagram of an OFDM two-branch diversity
         receiver using an interference canceller illustrating

30   conceptual construction of the present invention;

     FIG.5B is a block diagram of a parallel configuration of two-
         branch diversity interference cancellers illustrating

conceptual construction of the present invention;

FIG. 5C is a block diagram of an OFDM two-branch diversity
        receiver using an interference canceller with metric
        generators illustrating conceptual construction of
5   the present invention;

FIG. 6 is a block diagram of a two-branch diversity
        interference canceller illustrating a conceptual
        block of a replica generation type of the present
        invention;

10 FIG. 7 is a block diagram of a two-branch diversity
        interference canceller illustrating a replica
        generation type of the present invention;

FIG. 8 is a detailed block diagram of the interference
        canceller of Fig. 4;

15 FIG. 9 is an alternative detailed block diagram of the
        interference canceller of Fig. 4;

FIG. 10 is a detailed block diagram of the two-branch
        diversity interference canceller of Fig. 7;

FIG. 11 is an alternative block diagram of the two-branch
20   diversity interference canceller of Fig. 7;

FIG. 12 is an alternative embodiment of the OFDM two-branch
        diversity receiver of Fig. 5C;

FIG. 13 is a diagram showing an example of the configuration
        of a received burst signal;

25 FIG. 14 is a Bit Error Rate (BER) diagram showing the
        effectiveness of the present invention.

    A digital signal transmission multi-carrier scheme, such
as an orthogonal frequency division multiplexing scheme,
30 called OFDM scheme, reduces the effects of inter-symbol or
inter-block interference by making the block period much
larger than the delay spread of the radio channel. Even when

the delay spread becomes relatively large compared with the
length of the OFDM block period, the use of a cyclic prefix
preserves the orthogonality of the each sub-carrier channels
and eliminates inter-symbol interference (ISI) or inter-block

5   interference (IBI) between consecutive OFDM symbols. Thus, it
is a great advantage for high bit rate digital signal
transmissions to employ an OFDM scheme. In case of a
conventional single carrier per channel (SCPC) transmission
system, when the channel impulse response extends over many

10   symbols, the number of states to be defined in a maximum
likelihood sequence estimator becomes large. The number of
states increases exponentially as the excess delay normalized
by symbol duration increases. In case of the interference
signal canceller for single carrier per channel transmission

15   system, the number of state to be considered in a maximum
likelihood sequence estimator becomes huge. Applying an OFDM
scheme to a maximum likelihood sequence estimation (MLSE)
receiver is very promising and effective because the OFDM
scheme reduces the number of states to be considered in the

20   MLSE receiver. By employing an OFDM scheme, the MLSE can be
reduced in terms of the number of the state to be a simple
maximum likelihood estimator (MLE). There is no need to
perform the sequence estimation.

FIG. 2A and FIG. 2B illustrate in block diagrams the

25   conceptual configuration of a first embodiment of a receiver
8 according to the present invention for use in a digital
multi-carrier communication system such as an OFDM-system.
This receiver 8, as compared with the prior art receiver of
Fig. 1B, may also comprise a low pass filter 10, an analog-to

30   digital converter 11, a serial-to-parallel converter 12, a
remove cyclic extension device 13, a discrete Fourier
transform device 14, baseband demodulators and a parallel-to-

serial converter 16. In contrast to the prior art receiver
which only avoids inter-symbol interferences the receiver 8
according to the present invention features a configuration
wherein an interference signal canceller and signal detector

5   part (IC) 17 is connected between the discrete Fourier
transform device 14 the and parallel-to-serial converter 16.
The interference signal canceller and signal detector part
(IC) 17 cancels co-channel interference signals on each sub-
carrier channel by generating replica signals both of the

10   desired and interference signals. The interference signal
canceller and signal detector part (IC) 17 reduces the
interference and demodulates the desired signal. The outputs
of the interference signal canceller and signal detector part
(IC) 17 are parallel received data bit streams. The Parallel-

15   to-Serial (P/S) converter 16 converts the parallel received
data bit streams into a serial receive data bit stream.

FIG. 2B is a block diagram illustrating a concrete
configuration of the embodiment of the interference canceller
and signal detector part (IC) 17 in FIG. 2A. The FIG. 2B

20   embodiment is made up of a plurality of interference
cancellers (IC) 17_1, 17_2, 17_3, ..., 17_L, each of which is
associated to a respective sub-carrier channel.

FIG. 2C illustrates a concrete configuration of the
interference cancellers (IC) 17 shown in Fig. 2B for the l-th

25   sub-carrier channel, where $1 \leq l \leq L$ and L is a number of
sub-carriers. In FIG. 2C, the l-th interference canceller $17l$
is explained as an example. A transmitted symbol estimation
part 40 provides a metric generator 18 with a plurality of
transmitted symbol candidates. The metric generator 18

30   calculates metric values by using a received signal value
$y_l(n)$ at the terminal IN and the transmitted symbol
candidates and outputs the metric values which correspond to

each combination of the transmitted symbol candidates
provided by transmitted symbol estimation part 40. The
transmitted symbol estimation part 40 selects the most likely
combination set of the transmitted symbol candidates by using
5   the metric values provided by the metric generator 18, and
outputs the most likely combination set of the transmitted
symbol candidates to the terminal OUTd.

FIG. 3 shows in detail the metric generator 18 of the l-th
interference canceller 17l shown in Fig. 2C. In FIG. 3, the
10 metric generator 18 consists of a channel estimator 50, a
replica generator 20, an error estimation part 30 and a
metric calculator 60. In the channel estimator 50, the
channel parameter set, say, channel impulse responses both
for the desired and interference signals are stored. The
15 channel parameter set is fed to the replica generator 20. The
replica generator 20 generates a replica signal of the
received signals, which are the transmitted signals corrupted
by transmission channel distortions such as fading and
interference signals, say, co-channel signal which also
20 corrupted by the interference signal transmission channel
distortion such as fading. The error estimation part 30
calculates error signal e by using the above mentioned
replica signal and the received signal at the terminal IN.
The error signal e is used for the update of the channel
25 parameters in the channel parameter estimator 50. The error
signal e is also fed to the metric calculator 60. The metric
calculator 60 calculates the branch metric value. The branch
metric value is fed to the transmitted symbol estimation part
40. The transmitted symbol estimation part 40 provides the
30 set of the symbol candidates to the replica generator 20 and
gets the branch metric value which corresponds to the
provided set of the symbol candidates, from the metric

calculator 60, as a result. Then, the transmitted symbol
estimation part 40 determines the most likely combination set
of the candidate to be transmitted both at the desired and
the interference signal transmitters. The channel parameter
5   estimation part 50 received the most likely set of the
candidate to be transmitted and updates the channel
parameters both for the desired and the interference signals
by using the estimation error signal e which corresponds to
the most likely set of the candidate to be transmitted. In
10   updating channel parameters, the channel parameter estimation
part 50 may employ an adaptation algorithm such as Recursive
Least Squares (RLS) or Least Mean Square (LMS) algorithms.
The present invention may consider co-channel interference
signals as the above mentioned interference signals in a
15   cellular or personal communication system (PCS) radio
communication systems or digital audio broadcasting (DAB) and
digital video broadcasting (DVB) systems. In these
environments, fast channel adaptation such as RLS or LMS
algorithm would be required to track the fast-time-varying
20   channel parameters. The channel parameter estimation part 50
provides the updated channel parameters to the replica
generator 20 for the next replica generation.

FIG. 4 shows an example of the replica generator 20 of
the interference canceller 171. In this embodiment, for
25   explanation convenience, the replica generator 20 consists of
one desired signal estimation part 21 and two interference
signal estimation parts 22_1.and 22_2. But this scheme can be
easily extended to the case where there are more than one
desired and more than two interference signals. The channel
30   parameter set is divided into the channel parameters of the
desired and the interference signals. Each channel parameter
is fed to the corresponding signal estimation part 21, 22_1

and 22$_2$, respectively, in the replica generator 20. The
desired signal estimation part 21 generates the replica
signal of the desired signal, corrupted by the desired signal
transmission channel distortion such as fading, by using the
5   desired signal estimated channel parameter and the desired
signal symbol candidate. The interference signal estimation
part 22$_1$ generates the replica signal of the first
interference signal, called the interference signal #1
thereafter, by using the interference signal #1 estimated
10   channel parameter and the interference signal #1 symbol
candidate. The above mentioned interference signal #1 replica
is corrupted by the interference signal #1 transmission
channel distortion such as fading. The interference signal
estimation part 22$_2$ generates the replica signal of the
15   second interference signal, called the interference signal #2
thereafter, by using the interference signal #2 estimated
channel parameter and the interference signal #2 symbol
candidate. The above mentioned interference signal #2 replica
is also corrupted by the interference signal #2 transmission
20   channel distortion such as fading. In case of the multiple
interference signals more than 2, the interference signal
estimation part can be added to the replica generator 20, and
the channel estimator 50 and the transmitted symbol
estimation part 40 can also be easily extended. The replica
25   signals, say, from 21, 22$_1$ and 22$_2$, are summed up together in
a replica combining adder 23 to be the replica signal of the
received signal. The above mentioned replica signal contains
the desired signal, the interference signals #1 and #2, all
of which are corrupted by the corresponding transmission
30   channel fading effects.

　　　　FIG. 5A is a block diagram illustrating a concrete
configuration of a two-branch diversity receiver. This block

diagram illustrates only two-branch diversity reception
scheme, but this scheme can be easily extended to the scheme
that has more than two diversity branches. The received
baseband signal that corresponds to a diversity branch, say

5   diversity branch #1, is filtered with the low pass filter
10_1. This low pass filter 10_1 can be a matched filter that
corresponds to the transmitter filter in the transmitter. One
example of this filter is a typical raised cosine root roll
off filter. The output of the low pass filter 10_1 is fed to

10   an analog-to-digital (A/D) converter 11_1. The output of the
analog-to-digital converter 11_1 is fed to a serial-to-
parallel (S/P) converter 12_1 to get a block of received
signal samples which belong to the same OFDM symbol time
duration; i.e. OFDM symbol block. A cyclic extension remove

15   unit 13_1 removes a cyclic prefix to alleviate the effect of
inter-block interference (IBI). A discrete Fourier Transform
(DFT) unit 14_1 transforms a block of received time-domain
signal to received complex symbols corresponding to each sub-
carrier channels. At the diversity branch #2, the received

20   baseband signal is filtered with the low pass filter 10_2. The
output of the low pass filter is fed to the A/D converter
11_2. The sampled baseband signal is converted into a block of
received data samples by S/P converter 12_2. A cyclic
extension remove unit 13_2 removes the cyclic prefix and a DFT

25   unit 14_2 transforms a block of time-domain received signal
into received complex symbols on each sub-carrier channel. In
the interference canceller and signal detector part 17, these
received complex symbols are combined together on a sub-
channel by sub-channel basis. The outputs of the interference

30   signal canceller and signal detector part (IC) 17 are
parallel received data bit streams. A Parallel-to-Serial

(P/S) converter 16 converts the parallel received data bit streams into a serial receive data bit stream.

FIG. 5B illustrates a block diagram of parallel configuration of the interference canceller and detector part 17. In this embodiment, diversity combining is performed sub-channel by sub-channel. There are L independent interference cancellers $17_1...17_L$ in the interference canceller part 17, where L is the number of sub-carriers.

FIG. 5C illustrates a block diagram of the l-th interference canceller 17_1 of the interference canceller part17 shown in Fig. 5B, which employs two metric generators 18_1, 18_2 and a diversity combiner 70 for the diversity reception. A transmitted symbol estimation part 40 generates a plural set of the desired and interference signal candidates and provides the set to the metric generators 18_1 and 18_2. The metric generator 18_1 calculates metric values by using the l-th sub-channel received signal values $y_{l,1}(n)$ at the diversity branch #1 at the terminal IN1 and the transmitted symbol candidates provided by the transmitted symbol estimation part 40, and outputs the metric values which correspond to each combination set of the transmitted symbol candidates provided by transmitted symbol estimation part 40. The metric generator 18_2 calculates metric values by using the l-th sub-channel received signal values $y_{l,2}(n)$ at the diversity branch #2 at the terminal IN2 and the above mentioned transmitted symbol candidates provided by the transmitted symbol estimation part 40, and outputs the metric values which correspond to each combination of the transmitted symbol candidates provided by transmitted symbol estimation part 40. The diversity combiner 70 combines the metric values from the metric generator 18_1 and 18_2, and outputs diversity-combined metric values to the transmitted

symbol estimation part 40. The transmitted symbol estimation
part 40 selects the most likely combination set of the
transmitted symbol candidates by using the diversity-combined
metric value provided by the diversity combiner 70, and
5   outputs the most likely combination set of the transmitted
symbol candidates to the terminal OUTd.

FIG. 6 shows an example of the metric generators 18_1 and
18_2 of the l-th interference canceller 17_l for two-branch
diversity reception. The transmitted symbol estimation part
10   40 provides all possible combination set of the desired and
the interference symbol candidates to the metric generators
18_1 and 18_2 one by one. At the diversity branch #1, the
metric generator 18_1 consists of a channel estimator 50_1, a
replica generator 20_1, an error estimation part 30_1 and a
15   metric calculator 60_1. In the channel estimator 50_1, the
channel parameter set, say, channel impulse responses both
for the desired and interference signals are stored. The
channel parameter set is fed to the replica generator 20_1.
The replica generator 20_1 generates the replica signal of the
20   received signal, which is the received signal corrupted by
the distortion of the desired signal transmission channel,
say, fading and the interference signals, say, co-channel
signal which also corrupted by the interference signal
transmission channel distortion such as fading. The error
25   estimation part 30_1 calculates error signal $e_{l,m,1}$ by using the
above mentioned replica signal and the l-th subcarrier
received signal $y_{l,1}(n)$ at diversity branch #1 at the terminal
IN1. The error signal $e_{l,m,1}$ is used for the update of the
channel parameters in the channel parameter estimator 50_1.
30   The error signal $e_{l,m,1}$ is also fed to the metric calculator
60_1. The metric calculator 60_1 calculates a branch metric
value $b_{l,m,1}(n)$. The branch metric value $b_{l,m,1}(n)$ is fed to the

diversity combiner 70. At the diversity branch #2 in FIG. 6, the metric generator 18_2 consists of a channel estimator 50_2, a replica generator 20_2, an error estimation part 30_2 and a metric calculator 60_2. In the channel estimator 50_2, the

5   channel parameter set, say, channel impulse responses both for the desired and interference signals at the diversity branch #2 are stored. The channel parameter set is fed to the replica generator 20_2. The replica generator 20_2 generates the replica signal of the received signal, which is the

10   received signal corrupted by the distortion of the desired signal transmission channel, say, fading and the interference signals, say, co-channel signal which also corrupted by the interference signal transmission channel distortion such as fading. The error estimation part 30_2 calculates error signal

15     $e_{l,m,2}$ by using the above mentioned replica signal and the l-th subcarrier received signal $y_{l,2}(n)$ at diversity branch #2 at the terminal IN2. The error signal $e_{l,m,2}$ is used for the update of the channel parameters in the channel parameter estimator 50_2. The error signal $e_{l,m,2}$ is also fed to the

20   metric calculator 60_2. The metric calculator 60_2 calculates the branch metric value $b_{l,m,2}(n)$. The branch metric value $b_{l,m,2}(n)$ is fed to the diversity combiner 70. One embodiment example of the metric calculators 60_1 and 60_2 is absolute square circuits that calculate the absolute square value of

25   the error signals by

$$b_{l,m,j}(n) = \left| \varepsilon_{l,m,j} \right|^2 . \tag{1}$$

where l, m, j indicate the m-th set of the desired and interference signal candidates on l-th sub-channel at diversity branch j, and n indicate the time index at $t = nT$.

30   The two branch metric values $b_{l,m,1}(n)$ and $b_{l,m,2}(n)$ are combined in the diversity combiner 70 to be a combined branch metric in FIG.6. One embodiment example of the diversity combiner 70

is an adder that sums the metric values from the metric
generators 18_1 and 18_2 up together. For example, in case of
two branch diversity reception scheme, the sum of the metric
values $b_{1,m,1}(n) + b_{1,m,2}(n)$ is calculated as a combined metric.

5   In case of J diversity branch reception, the diversity-
combined metric value $b_{1,m}(n)$ for the m-th set of the
candidates on 1-th sub-channel is calculated as

$$b_{l,m}(n) = \sum_{j=1}^{J} b_{l,m,j} \; . \qquad\qquad (2)$$

The diversity-combined metric value $b_{1,m}(n)$ is fed to the
10   transmitted symbol estimation part 40. The transmitted symbol
estimation part 40 selects the most likely combination set of
the desired and the interference symbol candidate judging
from the corresponding combined branch metric value, and
outputs the most likely desired bit sequence to be
15   transmitted as the received bit sequence to the terminal
OUTd. The transmitted symbol estimation part 40 can be
configured so as to output interference bit sequences for
multi-user detection. The channel parameter estimation part
50_1 received the most likely set of the candidate to be
20   transmitted and updates the channel parameters at the
diversity branch #1 both for the desired and the interference
signals by using the estimation error signal $e_{1,m,1}$ which
corresponds to the most likely set of the candidate to be
transmitted. The channel parameter estimation part 50_2 also
25   received the above mentioned most likely set of the candidate
and updates the channel parameters at the diversity branch #2
both for the desired and the interference signals by using
the estimation error signal $e_{1,m,2}$ which corresponds to the
most likely set of the candidate to be transmitted. In
30   updating channel parameters both in the channel parameter
estimation parts 50_1 and 50_2, the channel parameter

estimation part 50_1 and 50_2 may employ an adaptation
algorithm such as Recursive Least Squares (RLS) or Least Mean
Square (LMS) algorithms. In this channel parameter update,
the set of signal symbol candidates both of the desired and
5   the interference signals are also used as reference signals
in the adaptation algorithm. The channel parameter estimation
parts 50_1 and 50_2 provide the updated channel parameters to
the replica generators 20_1 and 20_2, respectively, for the
next iteration of both the transmitted symbol estimation and
10   the channel parameter estimation. The diversity reception is
effective in discriminating or canceling the interference
signals because of the different characteristics of the
propagation channels.

        FIG. 7 shows an example of the replica generators 20_1
15   and 20_2 of the l-th interference canceller 171 for two-branch
diversity reception. In this embodiment, the replica
generator 20_1 consists of one desired signal estimation part
21_1, at least one interference signal estimation part, say,
22_{11}. In FIG. 7, one desired signal and two-interference
20   signal case are used for explanation. But this scheme can be
easily extended to the case where there are more than one
desired and more than two interference signals. The channel
parameter set is divided into the channel parameters of the
desired and the interference signals. Each channel parameter
25   is fed to the corresponding signal estimation part, say, 21_1,
22_{11} or 22_{21}, in the replica generator 20_1. The desired signal
estimation part 21_1 generates the replica signal of the
desired signal, corrupted by the desired signal transmission
channel distortion such as fading, by using the desired
30   signal estimated channel parameter and the desired signal
symbol candidate. The interference signal estimation part
22_{11} generates the replica signal of the interference signal

#1 by using the interference signal #1 estimated channel
parameter at diversity branch #1 and the interference signal
#1 symbol candidate. The above mentioned interference signal
#1 replica is also corrupted by the interference signal #1

5   transmission channel distortion such as fading. The
interference signal estimation part 22_{21} generates the
replica signal of the interference signal #2 by using the
interference signal #2 estimated channel parameter at
diversity branch #1 and the interference signal #2 symbol

10 candidate. The above mentioned interference signal #2 replica
is also corrupted by the interference signal #2 transmission
channel distortion such as fading. In case of the multiple
interference signals more than 2, the interference signal
estimation part can be added to the replica generator 20_1,

15 and the channel estimator 50_1 and the transmitted symbol
estimation part 40 can be easily extended. The replica
signals, say, from 21_1, 22_{11} and 22_{21}, are summed up together
in the replica combining adder 23_1 to be the replica signal
of the received signal. The above mentioned replica signal

20 contains the desired signal, the interference signal #1 and
#2, all of which are corrupted by the corresponding
transmission channel fading effects at diversity branch #1.
At diversity branch #2 in FIG. 7, the replica generator 20_2
consists of one desired signal estimation part 21_2, at least

25 one interference signal estimation part, say, 22_{12}. The
channel parameter set, which is provided by the channel
parameter estimation part 50_2, is divided into the channel
parameters of the desired and the interference signals. Each
channel parameter is fed to the corresponding signal

30 estimation part, say, 21_2, 22_{12} or 22_{22}, in the replica
generator 20_2. The desired signal estimation part 21_2
generates the replica signal of the desired signal, corrupted

by the desired signal transmission channel distortion such as
fading, by using the desired signal estimated channel
parameter at diversity branch #2 and the desired signal
symbol candidate. The interference signal estimation part

5   22_{12} generates the replica signal of the interference signal
#1 by using the interference signal #1 estimated channel
parameter at diversity branch #2 and the interference signal
#1 symbol candidate. The above mentioned interference signal
#1 replica is also corrupted by the interference signal #1

10   transmission channel distortion such as fading. The
interference signal estimation part 22_{22} generates the
replica signal of the interference signal #2 by using the
interference signal #2 estimated channel parameter at
diversity branch #2 and the interference signal #2 symbol

15   candidate. The above mentioned interference signal #2 replica
is also corrupted by the interference signal #2 transmission
channel distortion such as fading. In case of the multiple
interference signals more than 2, the interference signal
estimation part can be added to the replica generator 20_2 and

20   the channel estimator 50_2. The replica signals, say, from
21_2, 22_{12} and 22_{22}, are summed up together in the replica
combining adder 23_2 to be the replica signal of the received
signal. The above mentioned replica signal contains the
desired signal, the interference signal #1 and #2, all of

25   which are corrupted by the corresponding fading transmission
channel effects at diversity branch #2.

    FIG. 8 illustrates a detailed block diagram of the
interference canceller 17_1 of Fig. 4. In FIG. 8, the desired
signal and one interference signal are considered for

30   example. A desired signal estimation part 21 and an
interference signal estimation part 22 are realized by single
taps (multipliers only) 210 and 220, respectively. A

transmitted symbol estimation part 40 can be realized by a
modulation signal generator 41 for desired signals , the
modulation signal generator 42 for the interference signal, a
maximum likelihood estimator 43, training sequence memory

5   units 81 and 82, and training/tracking mode switches 44 and
45. In the maximum likelihood estimator 43, only the present
states both of the desired and interference signals are
considered.

It is assumed, for example, that each radio station

10   transmits an OFDM signal with a frame configuration as shown
in FIG. 13, wherein training signal blocks are added to the
beginning of an information data signal block (called pre-
amble). The training signal blocks can also be placed at the
intermediate portion (called mid-amble) or the end of an

15   information data signal blocks (called post-amble). The
training signal sequences are known sequence both at the
transmitter and at the receiver, and are used for initial
channel estimation both of the desired and the interference
signals, respectively. It is preferable that the training

20   patterns are unique patterns, which have high auto-
correlation of symbol sequence of their own but have low
cross-correlation value between each other. With the use of
training patterns whose symbol sequence patterns are
orthogonal to each other, it is possible to generate the

25   replica signals of the desired and interference signals
separately to such an extent that the replica signals have
high accuracy. When a plurality of interference signals are
present, their replica signals can be separately generated
with high accuracy by adopting the training symbol sequences

30   orthogonal to each other.

In the training mode, pre-known training bit sequences
$a_{1,1}(n)$ and $a_{2,1}(n)$ for the desired and interference signals,

respectively, which are stored as training patterns in the
training sequence memory units 81 and 82, respectively, are
fed by the switches 44 and 45 to the modulation signal
generator units 41, 42, respectively. The modulation signal
5   generator 41 transforms or maps the desired signal bit into
the complex modulation symbol $x_{1,1}(n)$. The modulation signal
generator 42 transforms or maps the interference signal bit
into complex modulation symbol $x_{2,1}(n)$. The output of the
modulation signal generators 41 and 42 are fed to a replica
10   generator 20 and a channel parameter estimation part 50. The
replica generator 20 is, for example, made up of a single
complex tap 210 which represents the desired signal
transmission channel parameter $\hat{h}_{1,l}(n-1)$, a single complex tap
220 which represents the interference signal transmission
15   channel parameter $\hat{h}_{2,l}(n-1)$ and a complex adder 230 which
combines the desired and the interference signal. The output
value of the desired signal estimation part 21 becomes
$x_{1,l}^{*}(n)\hat{h}_{1,l}(n-1)$, which represents the desired complex baseband
signal corrupted by the distortion of the desired signal
20   channel such as fading. The output value of the interference
signal estimation part 22 becomes $x_{2,l}^{*}(n)\hat{h}_{2,l}(n-1)$, which
represents the interference complex baseband signal corrupted
by the distortion of the interference signal channel such as
fading. The complex adder 230 sums these values up together
25   to output the replica of the received signal
$x_{1,l}^{*}(n)\hat{h}_{1,l}(n-1)+x_{2,l}^{*}(n)\hat{h}_{2,l}(n-1)$. An error estimation part 30 is
realized with a subtractor 32 in this embodiment. The
subtractor 32 calculates the estimation error signal $e_l(n)$ on
the l-th sub-carrier channel by

30
$$\varepsilon_l(n) = y_l(n) - \left[x_{1,l}^{*}(n)\hat{h}_{1,l}(n-1) + x_{2,l}^{*}(n)\hat{h}_{2,l}(n-1)\right] \qquad (3)$$

The estimation error signal $e_1(n)$ is fed to the channel
parameter estimation part 50. In this embodiment, the channel
parameter estimation part 50 is realized with a channel
estimator 51. The channel estimator 51 updates both the
desired and the interference signal transmission channel
parameters $\hat{h}_{1,I}(n-1)$ and $\hat{h}_{2,I}(n-1)$ by using adaptation algorithm,
say, Least-Mean-Squares (LMS) algorithm or Recursive Least
Square (RLS) algorithm with the estimation error $e_1(n)$. In
case of the update by LMS algorithm, an example of the
channel parameter update is performed as

$$\left[\hat{h}_{1,I}(n)\ \hat{h}_{2,I}(n)\right]^H = \left[\hat{h}_{1,I}(n-1)\ \hat{h}_{2,I}(n-1)\right]^H + \mu\left[x_{1,I}(n)\ x_{2,I}(n)\right]^H \varepsilon_I(n) \qquad (4)$$

The channel estimator 51 then outputs the updated channel
parameters $\hat{h}_{1,I}(n)$ and $\hat{h}_{2,I}(n)$ as tap coefficients to the complex
taps 210 and 220 for the next replica generation. After the
update of the tap coefficients, the training sequence memory
units 81 and 82 output the next training bit sequences
$a_{1,1}(n+1)$ and $a_{2,1}(n+1)$ to the modulation signal generators 41
and 42 through the switches 44 and 45. The above mentioned
replica generation process in the replica generator 20, the
error estimation process in the error estimation part 30 and
the channel parameter update process in the channel estimator
50 are iteratively performed until the end of the training
sequence. As the results, at the end of the training
sequence, the channel parameters converge in the channel
parameters which represent the real transmission channel
properties. The training mode is a process to get the channel
parameters of the desired and the interference signal
transmission channels with the training sequences.

       After the training mode, the tracking mode begins to
work. In the tracking mode, the information data signal
blocks in FIG. 13 are processed. During the tracking mode,

the switches 44 and 45 connect the maximum likelihood
estimator 43 to the modulation signal generators 41 and 42.
The maximum likelihood estimator 43 outputs sequentially all
the combination set of the desired and the interference

5   signal bit patterns $a_{1,1,m}(n)$ and $a_{2,1,m}(n)$ to the modulation
signal generators 41 and 42, where m is an index to the
possible set of the desired and the interference signal bit
patterns. For all values of m, that is, all possible
combination sets of the desired and the interference signal

10   bit patters, the following process is performed:

(1)   The modulation signal generator 41 transforms or maps
the desired signal bit patterns $a_{1,1,m}(n)$ into complex
modulation symbol $x_{1,1,m,}(n)$. The modulation signal
generator 42 transforms or maps the interference signal

15   bit patterns $a_{2,1,m}(n)$ into complex modulation symbol
$x_{2,1,m}(n)$.

(2)   The output of the modulation signal generators 41 and
42 are fed to the replica generator 20 and the channel
parameter estimation part 50.

20   (3)   The replica generator 20 generates the replica signal.
The single complex tap 210 stores the desired signal
transmission channel parameter $\hat{h}_{1,1}(n-1)$ which was obtained
at the former iteration. The single complex tap 220
stores the interference signal transmission channel

25   parameter $\hat{h}_{2,1}(n-1)$ which was obtained at the former
iteration. In case of the very beginning of the
tracking mode, the channel parameters obtained during
the training mode are used. The complex tap 210
calculates the value $x_{1,1,m}^{*}(n)\hat{h}_{1,1}(n-1)$ which represents the

30   desired complex baseband signal corrupted by the
distortion of the desired signal channel such as
fading. The complex tap 220 calculates the value

$\dot{x}_{2,l,m}(n)\hat{h}_{2,l}(n-1)$ which represents the interference complex
baseband signal corrupted by the distortion of the
interference signal channel such as fading. The complex
adder 230 sums these values up together to output the
5   replica $\hat{y}_{l,m}(n)$ of the received signal as

$$\hat{y}_{l,m}(n) = \dot{x}_{1,l,m}(n)\hat{h}_{1,l}(n-1) + \dot{x}_{2,l,m}(n)\hat{h}_{2,l}(n-1) . \tag{5}$$

(4)   The error estimation part 30 calculates the estimation
      error signal. The subtractor 32 calculates the
      estimation error signal $e_{1,m}(n)$ on the 1-th sub-carrier
10   channel by

$$\varepsilon_{l,m}(n) = y_l(n) - \hat{y}_{l,m}(n) \tag{6}$$

(5)   The error signal $e_{1,m}(n)$ is fed to the metric calculator
      60. In the metric calculator 60, the absolute-square
      circuit 61 calculates branch metric $b_{l,m}(n)$ by

15    $$b_{l,m}(n) = \left| \varepsilon_{l,m}(n) \right|^2 . \tag{7}$$

where 1 and m indicate the m-th set of the desired and
interference signal candidates on 1-th sub-channel.

The maximum likelihood estimator 43 selects the most
20   likely set $a_{1,1}(n)$ and/or $a_{2,1}(n)$ of the desired and
interference signal candidates and outputs to the terminal
OUTd. In case of the branch metric defined in equation (7),
the maximum likelihood estimator 43 selects the most likely
set $a_{1,1,m}(n)$ and/or $a_{2,1,m}(n)$ so as to minimize the $b_{l,m}(n)$ with
25   regard to the index m. The estimation error signal $e_{1,m'}(n)$ is
fed to the channel parameter estimation part 50, where m'
gives the minimum $b_{l,m}(n)$ value in equation (7) for all
possible m's. The channel estimator 51 updates both the
desired and the interference signal transmission channel
30   parameters $\hat{h}_{1,l}(n-1)$ and $\hat{h}_{2,l}(n-1)$ by using adaptation algorithm,
say, Least-Mean-Squares (LMS) algorithm or Recursive Least

Square (RLS) algorithm with the estimation error $e_{1,m'}(n)$ and
the selected set of $a_{1,1,m'}(n)$ and/or $a_{2,1,m'}(n)$. In case of
updating by LMS algorithm, an example of the channel
parameter update is performed as

5
$$\left[\hat{h}_{1,l}(n)\hat{h}_{2,l}(n)\right]^H = \left[\hat{h}_{1,l}(n-1)\hat{h}_{2,l}(n-1)\right]^H + \mu\left[x_{1,l,m}(n)x_{2,l,m}(n)\right]^H \varepsilon_{l,m}(n) \qquad (8)$$

where m is a step size parameter.

The channel estimator 51 then outputs the updated channel
parameters $\hat{h}_{1,l}(n)$ and $\hat{h}_{2,l}(n)$ as tap coefficients to the complex
taps 210 and 220 for the next replica generation. After the
10   update of the tap coefficients, the maximum likelihood
estimator 43 outputs sequentially all the combination set of
the desired and the interference signal bit patterns
$a_{1,1,m}(n+1)$ and $a_{2,1,m}(n+1)$ to the modulation signal generators
41 and 42, where m is an index to the possible set of the
15   desired and the interference signal bit patterns. For all
values of m, the above mentioned processes from (1) to (5)
are performed again. When the transmission channels do not
vary fast in time, the channel parameter update process
during the tracking mode can be stopped.

20   For generalization, it is assumed that a desired signal
station user and (K-1) interference signal station users
exist on the same OFDM channel. Let the channel transfer
function on l-th sub-carrier of k-th user be $h_{k,l}$, the
received signal on the l-th sub-carrier channel can be
25   expressed as follows;

$$y_l(n) = \sum_{k=1}^{K} h_{k,l}(n)x_{k,l}(n) + n_l(n) \qquad (9)$$

where $y_l(n)$ is the received signal on the l-th sub-carrier,
$x_{k,l}(n)$ is the transmitted symbol on l-th sub-carrier of k-th
user, and $n_l(n)$ is filtered thermal noise on the l-th sub-
30   carrier. The index n indicate the n-th time instant. FIG. 8
corresponds to the concrete embodiment in case of K=2.

During the training mode, the training process is performed. In this process, the switches 44 and 45 are connected to the individual training sequence memory units (81 and 82) which store the known training sequence, in order to make the tap coefficients $\hat{h}_{k,l}(n)$ converge into the values which represent the channel transfer function of the corresponding desired and interference signal transmission channels. The modulation signal generators 41 and 42 generate corresponding training complex modulation symbols $x_{k,l}(n)$. These symbols are fed to the multipliers 21 and 22. The output of the multipliers 210 and 220 become the replica signals of the desired and interference signals, respectively. These replica signals are summed up together at the adder 230 to become the replica signal $\hat{y}_l(n)$ of the received signal which are the mixture of the desired and the interference signals as

$$\hat{y}_l(n) = \sum_{k=1}^{K} x^*_{k,l}(n)\hat{h}_{k,l}(n-1) \tag{10}$$

where * denotes complex conjugation. $\hat{h}_{k,l}(n-1)$ and $x_{k,l}(n)$ denote, respectively, the k-th user's estimated complex channel response at time instant $(n-1)T$ and the modulation training symbol of the k-th user on l-th sub-channel at time instant nT. T is the OFDM block duration.

This replica signal $\hat{y}_l(n)$ is subtracted at the subtractor 32 from the actual received signal $y_l(n)$ and the error signal $e_l(n)$ on l-th sub-carrier channel is obtained as follows;

$$\varepsilon_l(n) = y_l(n) - \hat{y}_l(n) \tag{11}$$

The estimated channel response vector (tap coefficient vector) $H_l(n)$ both for the desired and $(K-1)$ interference signals is given by

$$H_l^H(n) = \begin{bmatrix} \hat{h}^*_{1,l} & n & \hat{h}^*_{2,l} & n & \dots & \hat{h}^*_{K,l} & n \end{bmatrix} \tag{12}$$

where ^{H} denotes complex conjugation and transposition.

Similarly, the modulation training symbol vector X_l (n) for the desired and $(K-1)$ interference signals is given by

$$X_l^H(n) = \begin{bmatrix} x_{l,}^{\cdot} \ n, & x_{2,}^{\cdot} \ n, & \cdots & x_{r,}^{\cdot} \ n \end{bmatrix} \qquad (13)$$

The channel estimator 51 updates the estimated channel response vector $H_l(n)$ by an adaptation algorithm such as RLS, LMS or a similar adaptation algorithm. Here, for example, the update of the estimated channel response vector $H_l(n)$ using the LMS algorithm is explained. The channel estimator 51 updates the channel response vector $H_l(n)$ using both the known modulation training symbol vector $X_l(n)$ and the error signal $e_l(n)$ as follows;

$$H_l^H(n) = H_l^H(n-1) + \mu X_l^H(n)\varepsilon_l(n) \qquad (14)$$

where m is a step size parameter.

After the above mentioned training process, the information data signal block is processed. At the beginning of the information data signal period, the estimated channel response $H_l(n-1)$ obtained in the training process is used as a initial value of the estimated channel response vector $H_l(n-1)$.

The maximum likelihood estimator 43 outputs the possible combinations of the desired signal and the interference signal bit candidates to the modulation signal generators 41 and 42. This combination set of the desired signal and the interference signal complex modulation symbols can be expressed as the modulation vector candidate $X_{l,m}(n)$ for the desired and $(K-1)$ interference signals on the l-th sub-carrier channel with a candidate index number of m as follows;

$$X_{l,m}^H(n) = \begin{bmatrix} x_{l,l,m_1}^{\cdot}(n), & x_{2,l,m_2}^{\cdot}(n), & \cdots & x_{K,l,m_K}^{\cdot}(n) \end{bmatrix} \qquad (15)$$

where m is a combined symbol index number (possible candidate number) defined as follows;

$$m = \sum_{k=1}^{K} M^{k-1} m_k \qquad (16)$$

where M is a number of messages, for example $M = 4$ in case of QPSK signaling, and m_k is the k-th user signal message symbol index number which is an integer of $0 = m_k = (M-1)$, thus m takes an integer value ranging $0 = m = (M^K-1)$.

For example, in case of BPSK signaling modulation, the complex message symbol $x_{k,l,m_k}(n)$ at the time instant nT is as follows;

$$x_{k,l,m_k}(n) = 1 \qquad (m_k = 0)$$
$$= -1 \qquad (m_k = 1) \qquad (17)$$

Hence with two users, i.e. the desired signal station and one interference signal station, the modulation vector candidate $\mathbf{X}_{1,m}(n)$ $(0 = m = 3)$ at time instant nT takes one of the following vectors;

$$\mathbf{X}_{l,0}^{H}(n) = \begin{bmatrix} +1 & +1 \end{bmatrix}$$
$$\mathbf{X}_{l,1}^{H}(n) = \begin{bmatrix} +1 & -1 \end{bmatrix}$$
$$\mathbf{X}_{l,2}^{H}(n) = \begin{bmatrix} -1 & +1 \end{bmatrix} \qquad (18)$$
$$\mathbf{X}_{l,3}^{H}(n) = \begin{bmatrix} -1 & -1 \end{bmatrix}$$

In the case of QPSK signaling modulation, for example, the complex message symbol $x_{k,l,m_k}(n)$ at the time instant nT is as follows;

$$x_{k,l,m_k}(n) = \frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \qquad (m_k = 0)$$
$$= -\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \qquad (m_k = 1)$$
$$= -\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \qquad (m_k = 2) \qquad (19)$$
$$= \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \qquad (m_k = 3)$$

Hence in case of QPSK signaling modulation with two users, the modulation vector candidates $\mathbf{X}_{1,m}(n)$ $(0 = m = 15)$ at time instant nT are the following vectors;

$$x_{l,0}^{H}(n) = \left[\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,1}^{H}(n) = \left[\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,2}^{H}(n) = \left[\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,3}^{H}(n) = \left[\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}}\right]$$

5

$$x_{l,4}^{H}(n) = \left[-\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,5}^{H}(n) = \left[-\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,6}^{H}(n) = \left[-\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,7}^{H}(n) = \left[-\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}}\right]$$

10

$$x_{l,8}^{H}(n) = \left[-\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,9}^{H}(n) = \left[-\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right] \qquad (20)$$

$$x_{l,10}^{H}(n) = \left[-\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,11}^{H}(n) = \left[-\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,12}^{H}(n) = \left[\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

15

$$x_{l,13}^{H}(n) = \left[\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad -\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}}\right]$$

$$x_{l,14}^{H}(n) = \left[\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \right]$$

$$x_{l,15}^{H}(n) = \left[\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \right]$$

5   The replica signal of the received signal at the output of
the adder 230 becomes $X_{l,m}^{H}(n)\cdot H_{l}(n)$. The error signal $e_{l,m}(n)$ for
m-th candidate on the l-th sub-carrier channel becomes as
follows;

$$\varepsilon_{l,m}(n) = y_l - X_{l,m}^{H}(n)\cdot H_l(n) \qquad\qquad (21)$$

10   The absolute-squared error signal $\left|\varepsilon_{l,m}(n)\right|^2$ is calculated for
each candidate index m in the metric calculation part 61 and
is used as a metric $b_{l,m}(n)$ in the maximum likelihood
estimator 43 to determine the most likely candidate so as to
minimize the squared error signal value $b_{l,m}(n)$ as follows;

$$b_{l,m_{min}}(n) = \underset{m}{Min}\left(\left|\varepsilon_{l,m}(n)\right|^2\right) \qquad\qquad (22)$$

where m_{min} is the index m which gives the minimum value of
$b_{l,m}(n)$. The set of the desired and interference signals which
has been transmitted most likely as complex symbols can be
determined with m_{min} according the index number defined in the
20   equation (16).

When the transmission channel variation is relatively slow
compared to the OFDM symbol rate, the channel response vector
$H_l(n)$ can be used constantly even in the information data
signal block. The channel response vector update process can
25   be stopped after the training process. This case further can
reduce the complexity of the embodiment in terms of the
signal processing.

When the transmission channel varies very rapidly, such as
the mobile radio channel for example, the channel response

vector $H_l(n)$ can be updated OFDM-block-by-block by using an
adaptation algorithm, such as RLS, LMS or other similar
adaptation algorithms. Here, the update of the channel
response vector $H_l(n)$ by the LMS algorithm is explained as an
example. During the information data signal blocks, the
channel estimator 51 updates the estimated channel response
vector $H_l(n)$ using both the determined modulation symbol
vector $X_{l,m_{min}}(n)$ and the error signal $\varepsilon_{l,m_{min}}(n)$ obtained for the
candidate having the index m_{min} as follows;

$$H_l^H(n) = H_l^H(n-1) + \mu X_{l,m_{min}}^H(n)\varepsilon_{l,m_{min}}(n) \tag{23}$$

where m is a step size parameter.
The updated channel response vector $H_l(n)$ is used for the
replica generation at next step in Equation (21). The
extension to the case where a plurality of the interferer is
present, is straightforward by adding extra interference
signal estimation parts same as 22, and modulated signal
generating parts, same as 42.

FIG. 9 illustrates another embodiment of the interference
canceller of Fig. 4. In FIG. 9, the channel parameter
estimation part 50 is realized with another channel estimator
52. An example of the channel estimator 52 is a complex
correlator which calculates complex cross-correlation between
the received signal and the training sequence and determines
the channel parameters. In this embodiment, during the
training mode, the switch 44 and 45 connect the training
sequence memory units 81 and 82 to the modulation signal
generators 41 and 42, respectively in order to provide the
complex modulation symbols $x_{1,l}(n)$ and $x_{2,l}(n)$ to the channel
estimator 52. The received-signal/error-signal switch 53
connects the channel estimator 52 to a terminal IN in order
for the channel estimator 52 to get the received signal
$y_l(n)$. In the channel estimator 52, cross-correlation between

the received signal $y_1(n)$ and the complex modulation symbols
both of the desired and the interference signal are
calculated over the training period, and then the tap
coefficients both for the desired and the interference signal

5   are determined. In the tracking mode, the received-
signal/error-signal switch 53 connects the channel estimator
52 to the subtractor 32 so that the channel estimator 52 gets
an estimation error signal. In the tracking mode, this
embodiment works in the same manner as the embodiment

10   described in FIG. 8. When the transmission channels do not
vary fast in time, the channel parameter update process
during the tracking mode can be stopped. The channel
parameters can be used during the tracking mode in which the
information data signal blocks are sent.

15   FIG. 10 illustrates a concrete embodiment of the two-
branch diversity interference canceller of Fig. 7. In FIG.
10, there are two metric generators 18_1 and 18_2, each of
which consists of the channel parameter estimation parts 50_1
and 50_2, respectively, the desired signal estimation part 21_1

20   and 21_2, the interference signal estimation parts 22_1 and 22_2
and the error estimation part 30_1 and 30_2. In case of a J-
branch diversity reception scheme, there are J metric
generators; 17_1, 17_2, .., 17_J. In FIG. 10 let the j-th input
received signal at the j-th metric generator input terminal

25   INj, the j-th error signal, the j-th channel response vector
and the j-th modulation vector at the time instant nT be
$y_{1,j}(n)$, $e_{1,j}(n)$, $\mathbf{H}_{1,j}(n)$ and $\mathbf{X}_1(n)$, the error signal $e_{1,m,j}(n)$
on the 1-th sub-carrier channel during the training period is
calculated by the following equation;

30                  $$\varepsilon_{1,j}(n) = y_{1,j} - \mathbf{X}_1^H(n) \cdot \mathbf{H}_{1,j}(n-1)$$ (24)

where $X_l^H(n)$ is provide by training sequence memory units 81 and 82 and is written by the same equation as the equation (13). The j-th channel response vector $H_{l,j}(n)$ is written by

$$H_{l,j}^H(n) = \begin{bmatrix} \hat{h}_{1,l,j}^* & n & \hat{h}_{2,l,j}^* & n & \dots & \hat{h}_{K,l,j}^* & n \end{bmatrix}, \qquad (25)$$

where ^{H} denotes complex conjugation and transposition and $\hat{h}_{k,l,j}(n)$ denotes the k-th user's channel response at the j-th diversity branch on l-th sub-channel.

The j-th channel estimator 51j updates the j-th channel response vector $H_{l,j}(n)$ by adaptation algorithm such as LMS, RLS, or other similar adaptation algorithm. We explain here, for example, the update by LMS algorithm. The channel estimator 51j updates the channel response vector $H_{l,j}(n)$ using the known modulation training symbol vector $X_l(n)$ and the error signal $\varepsilon_{l,j}(n)$ as follows;

$$H_{l,j}^H(n) = H_{l,j}^H(n-1) + \mu X_l^H(n)\varepsilon_{l,j}(n) \qquad (26)$$

where m is a step size parameter.

In tracking mode, let the m-th modulation vector candidate on the l-th subcarrier channel at the time instant nT be $X_{l,m}(n)$, the m-th estimation error signal $e_{l,m,j}(n)$ on the l-th subcarrier channel at the j-th diversity branch is calculated by the following equation;

$$\varepsilon_{l,m,j}(n) = y_{l,j} - X_{l,m}^H(n) \cdot H_{l,j}(n-1) \qquad (27)$$

The metric combiner 71 sums up together the m-th candidate squared error signals $\left| \varepsilon_{l,m,j}(n) \right|^2$ to perform diversity combining by the following equation;

$$b_{l,m}^{'}(n) = \sum_{j=1}^{J} \left| \varepsilon_{l,m,j}(n) \right|^2 \qquad (28)$$

The maximum likelihood estimator 43 determines the most likely candidate so as to minimize the combined metric $b_{l,m}(n)$ which was calculated by equation (28), as follows;

$$b_{l,min}(n) = \underset{m}{Min}\ b_{l,m}(n) \qquad (29)$$

where m_{min} is the index m which gives the minimum value of
$b_{l,m}(n)$. The set of the desired and interference signals which
most likely has been transmitted as complex symbols can be
determined with m_{min} according to the index number defined in
the equation (16). When the transmission channels do not vary
fast in time, the channel parameter update process during the
tracking mode can be stopped. The channel parameters can be
used during the tracking mode in which the information data
signal blocks are sent. When the transmission channels vary
fast in time, the channel parameters can be updated during
tracking mode, the channel estimator 51_j updates the channel
response vector $H_{l,j}(n-1)$ using the determined modulation
symbol vector $X_{l,m_{min}}(n)$ and the error signal $\varepsilon_{l,m_{min},j}(n)$ as follows;

$$\mathbf{H}_{l,j}^H(n) = \mathbf{H}_{l,j}^H(n-1) + \mu \mathbf{X}_{l,m_{min}}^H(n)\varepsilon_{l,m_{min},j}(n) \qquad (30)$$

where m is a step size parameter.

FIG. 11 illustrates an alternative embodiment of the two-
branch diversity interference canceller of Fig. 7. In FIG.
11, the channel parameter estimation parts 50_1 and 50_2 are
realized with other channel estimators 52_1 and 52_2,
respectively. An example of the channel estimators 52_1 and
52_2 are complex correlators which calculate complex cross-
correlation between the received signal and the training
sequence, and which determine the channel parameters. In this
embodiment, during the training mode, the switches 44 and 45
connect the training sequence memory units 81 and 82 to the
modulation signal generators 41 and 42, respectively in order
to provide the complex modulation symbols $x_{1,1}(n)$ and $x_{2,1}(n)$
to the channel estimators 52_1 and 52_2. The received-
signal/error signal switches 53_1 and 53_2 connect the channel
estimators 52_1 and 52_2 to the terminal IN1 and IN2 so that
the channel estimators 52_1 and 52_2 get the received signal
$y_{1,1}(n)$ and $y_{1,2}(n)$, respectively. In the channel estimator

52_1, cross-correlation between the received signal $y_{1,1}(n)$ and the complex modulation symbols, say, $x_{1,1}(n)$ and $x_{2,1}(n)$ of the desired and the interference signals, respectively, are calculated over the training period, and then the tap

5   coefficients, say, $\hat{h}_{1,1,1}(n-1)$ and $\hat{h}_{2,1,1}(n-1)$ for the desired and the interference signal, respectively, are determined. In the channel estimator 52_2, cross-correlation between the received signal $y_{1,2}(n)$ and the complex modulation symbols $x_{1,1}(n)$ and $x_{2,1}(n)$ of the desired and the interference signals,

10   respectively, are calculated over the training period, and then the tap coefficients, say, $\hat{h}_{1,1,2}(n-1)$ and $\hat{h}_{2,1,2}(n-1)$ for the desired and the interference signal, respectively, are determined.

      In the tracking mode, the received-signal/error-signal

15   switches 53_1 and 53_2 connect the channel estimators 52_1 and 52_2 to the subtractors 32_1 and 32_2 so that the channel estimators 52_1 and 52_2 get estimation error signals. In the tracking mode, this embodiment works in the same manner as, say, the embodiment described in FIG. 10. When the

20   transmission channels do not vary fast in time, the channel parameter update process during the tracking mode can be stopped. The channel parameters can be used during the tracking mode in which the information data signal blocks are sent.

25   FIG. 12 illustrates an alternative embodiment of the OFDM two-branch diversity receiver of Fig. 5C. In FIG. 12, another embodiment of the diversity combiner 70 is depicted. The diversity combiner 70 is made up of a diversity combining adder 71, multipliers 72_1 and 72_2, a branch combining weight

30   controller 73. The branch combining weight controller 73 receives channel information of received signals at diversity branches such as received signal strength information or

other interference strength information, and determines
weight-coefficients that weight each metric value of the
diversity branch. The multipliers 72_1 and 72_2 receive weight-
coefficients from the branch combining weight controller.

5   Then, the multipliers 72_1 and 72_2 multiply each metric value
from each metric generator by corresponding weight-
coefficient, and output metric values to the adder 71. The
adder 71 sums the weighted metric values up together and
outputs a combined metric value to the transmitted symbol

10   estimation part 40.

        FIG. 14 depicts the bit error rate (BER) performance of
the present invention showing the effectiveness of the
present invention. FIG. 14 shows that the average bit error
rate of a receiver according to the present invention under

15   the Rayleigh fading condition is less than 1.0×10^{-2} for
average Carrier-to-Interference Ratio (CIR) =-5 dB, where the
Co-Channel Interference (CCI) signal is stronger than the
desired signal by 5 dB. The effectiveness of the present
invention can also be shown by the fact that the average BER

20   value of the receiver according to the present invention at
an average CIR of 0 dB is less than 1.0×10^{-2} while that of a
conventional signal detector in an OFDM receiver is 0.5.

Claims

1.   A receiver for use in a digital multi-carrier
     communication system, comprising
5   a)   at least one receiving branch (#1, #2), wherein each
          receiving branch comprises demodulating means (0; O_1,
          O_2) for converting a received serial multi-carrier
          signal including at least one desired and interference
          signal into a plurality (L) of sub-carrier signals,
10   and
     b)   a plurality (L) of interference cancellers (17_1-17_L)
          each of which is associated to a respective one of
          said sub-carrier signals for canceling co-channel
          interference.

15

2.   The receiver according to claim 1, wherein the digital
     multi-carrier communication system is an OFDM-system.

3.   The receiver according to claim 2, wherein each
20   demodulating means (0; O_1, O_2) comprises
     a serial-to-parallel converter (12; 12_1, 12_2) for
     converting the received serial multi-carrier signal into
     parallel OFDM signal blocks,
     means for removing cyclic extensions inserted into the
25   multi-carrier signal to be transmitted to remove inter-
     block interference,
     Discrete Fourier Transform means for converting each OFDM
     signal block into a plurality of OFDM sub-carrier
     signals, and wherein
30   the outputs of the interference cancellers (17_1-17_L) are
     fed to a serial-to-parallel converter (16).

4.   The receiver of any one of claims 1 to 3, wherein each
      interference canceller (17_1-17_L) comprises
      a transmitted symbol estimation part (40) connected to a
      metric generator $(18; 18_1, 18_2)$ for applying a set of
5   symbol candidates both for the at least desired and
      interference signals to the metric generator $(18; 18_1,$
      $18_2)$ and for receiving metric values generated by the
      metric generator $(18; 18_1, 18_2)$ by using a received sub-
      carrier signal and said set of symbol candidates, wherein
10   said transmitted symbol estimation part (40) determines
      the most likely set of symbol candidates by using the
      metric values.

5.   The receiver of claim 4, wherein the metric generator
15    $(18; 18_1, 18_2)$ comprises
      a channel parameter estimation part $(50; 50_1, 50_2)$ for
      estimating signal transmission channel parameters both of
      the at least one desired and interference signals by
      using the set of the desired and the interference signal
20   symbol candidates provided by said transmitted symbol
      estimation part (40) and an estimation error signal
      provided by an error estimation part $(30; 30_1, 30_2)$,
      a replica generator $(20; 20_1, 20_2)$ for generating a
      replica signal from both of the desired and the
25   interference signals by using the set of the desired and
      the interference signal symbol candidates and the desired
      and the interference signal channel parameters provided
      by said channel parameter estimation part $(50; 50_1, 50_2)$,
      wherein
30   said error estimation part $(30; 30_1, 30_2)$ generates the
      estimation error signal by using said received sub-
      carrier signal and the replica signal

and a metric calculator (60, 60₁, 60₂) connected to said
transmitted symbol estimation part (40) for generating
metric values from the estimation error signal.

5   6.   The receiver of claim 5, wherein the replica generator
         (20; 20₁, 20₂) of each metric generator (18; 18₁, 18₂)
         comprises
         a desired signal estimation part (21; 21₁, 21₂) for
         generating the replica of the desired signal by using the
10   channel parameter of the desired signal and a desired
         signal symbol candidate provided by the transmitted
         symbol estimation part (40),
         at least one interference signal estimation part (22₁,
         22₂) each for generating a replica of a respective
15   interference signal by using the interference signal
         transmission channel parameters and interference signal
         symbol candidates provided by the transmitted symbol
         estimation part (40),
         a replica combining adder (23; 23₁, 23₂) for combining
20   the generated replicas of the desired and interference
         signals and outputting the combined replica to the error
         estimation part (30; 30₁, 30₂).

     7.   The receiver of claim 4, 5 or 6, wherein
25   the transmitted symbol estimation part (40) comprises
          a first modulation signal generator (41) for generating
          desired signal complex modulation symbols
          at least one second modulation signal generator (42) for
          generating interference signal complex modulation
30   symbols, and wherein
          the replica generator (20; 20₁, 20₂) of each metric
          generator (18; 18₁, 18₂) comprises

a first complex multiplier (210; 210_1, 210_2) for
multiplying the output signal of the first modulation
signal generator (41) with the desired signal
transmission channel parameter generated by the channel

5   parameter estimation part (50; 50_1, 50_2),
at least one second complex multiplier (220; 220_1, 220_2)
for multiplying the output signal of the respective
second modulation signal generator (41) with the
respective interference signal transmission channel

10   parameter generated by the channel parameter estimation
part (50; 50_1, 50_2),
a replica combining adder (230; 230_1, 230_2) connected to
said first and at least one second multiplier for
summing the desired and interference signal replicas.

15

8.   The receiver of claim 7, wherein the transmitted symbol
estimation part (40) comprises
a first training sequence memory unit (81) for storing a
desired signal training bit sequence and for generating a

20   set of training bits
at least one second training sequence memory unit (82)
each of which stores an interference signal training bit
sequence and each of which generates a set of training
bits of a corresponding interference signal,

25   a maximum likelihood estimator (43),
a first switch (44) for connecting the first training
sequence memory unit (81) during a training period and a
respective output of the maximum likelihood estimator
(43) during a tracking period to the first modulation

30   signal generator (41),
at least a second switch (45) for connecting the
respective second training sequence memory unit (81)

during a training period and a respective output of the
maximum likelihood estimator (43) during a tracking
period to the respective second modulation signal
generator (41).

9.   The receiver of claim 8, wherein the channel parameter
     estimation part (50; 50_1, 50_2) comprises
     a channel estimator (51; 51_1, 51_2) having inputs
     connected to the first and second modulation signal
     generators (41, 42) and to the error estimation part (30;
     30_1, 30_2) and outputs connected to the first and second
     complex multiplier (210; 210_1, 210_2) for estimating
     and/or updating said desired and interference
     transmission channel parameters by using an adaptation
     algorithm.

10. The receiver of claim 9, wherein the adaption algorithm
     is a recursive adaption algorithm, a Recursive-Least-
     Squares (RLS) algorithm or a Least-Mean-Square (LMS)
     algorithm.

11. The receiver of claim 8, wherein the channel parameter
     estimation part (50; 50_1, 50_2) comprises
     a channel estimator (52; 52_1, 52_2) having inputs
     connected to the first and second modulation signal
     generators (41, 42) and to a switch (53; 53_1, 53_2) and
     outputs connected to the first and second complex
     multiplier (210; 210_1, 210_2), wherein
     said switch controlable supplies the received sub-carrier
     signal which is also applied to the error estimation part
     (30; 30_1, 30_2) or the error signal generated by the error
     estimation part (30; 30_1, 30_2) to the channel

estimator $(52; 52_1, 52_2)$.

12. The receiver of anyone of the claims 1 to 11, wherein
     the metric calculator $(60; 60_1, 60_2)$ comprises
     an absolute-square circuit $(61; 61_1, 61_2)$ for
     calculating an absolute-squared value of the applied
     error signal.

13. The receiver of anyone of the claims 5 to 12, wherein
     the error estimation part $(30; 30_1, 30_2)$ comprises
     a subtractor $(32; 32_1, 32_2)$ for subtracting said replica
     signal provided by the replica combining adder $(230;
     230_1, 230_2)$ from said respectively received sub-carrier
     signal to generate said estimation error signal.

14. The receiver of any one of the claims 1 to 13, wherein
     the receiver is a multi-branch diversity receiver
     comprising a plurality (L) of interference cancellers
     (17_1-17_L), each of which comprises
     a transmitted symbol estimation part (40) connected to a
     number (#1, #2)) of metric generators $(18_1, 18_2)$ for
     applying a set of symbol candidates both for the desired
     and interference signals to the metric generators $(18;
     18_1, 18_2)$, wherein the number of metric generators
     corresponds to the number of receiving branches, wherein
     each metric generator $(18; 18_1, 18_2)$ generates metric
     values by using a respective received sub-carrier signal
     of a different diversity branch and said set of symbol
     candidates, and
     a diversity combiner (70) connected to said metric
     generator (40) for combining the metric values received
     from the metric generators $(18_1, 18_2)$, wherein said

transmitted symbol estimation part (40) determines the
most likely set of symbol candidates both for the desired
and interference signals to be transmitted by using the
metric values received from the diversity combiner.

15.   The receiver of claim 14, wherein the diversity combiner
       (70) comprises a diversity combining adder (71).

16.   The receiver of claim 14, wherein the diversity combiner
       (70) comprises
       a branch combining weight controller (73) which receives
       a respective received sub-carrier signal on each
       receiving branch for computing combining weight-
       coefficients and outputting said weight-coefficients,
       a plurality of multipliers (72_1, 72_2) each connected to a
       respective metric generator (18_1, 18_2),
       a diversity combining adder (71) having inputs connected
       to the multipliers (72_1, 72_2) and an output connected to
       the transmitted symbol estimation part (40).

17.   The receiver of anyone of the claims 1 to 16, wherein
       the transmitted symbol estimation part (40) of each
       interference canceller is adapted to output information
       data of the desired signal and the interference signals,
       thereby forming a multi-user detection receiver.

18.   A digital multi-carrier communication system comprising
       a plurality of transmitters and a plurality of receivers
       (8) according to anyone of the claims 1 to 17.

19. A method for canceling interference signals in a multi-
carrier signal arrived at a receiver of anyone of the
claims 1 to 17, said method comprising the steps:

a) Receiving a serial baseband multi-carrier signal
containing desired and interference signals over at
least one receiving branch;

b) converting the received multi-carrier signal into a
plurality of baseband sub-carrier signals;

c) canceling of co-channel interference in each sub-
carrier signal,

d) converting the sub-carrier signals to a multi-
carrier output signal comprising the desired signal.

20. The method of claim 19 wherein for each sub-carrier
signal the canceling step c) comprises the further steps:

a) generating sequentially a plurality of sets of
desired signal symbol sequence candidates and
interference signal symbol sequence candidates;

b) generating metric values from a respective received
sub-carrier signal and said plurality of sets of
desired and interference signal symbol candidates;

c) performing a maximum likelihood estimation by using
the metric values in order to determine the most
likely set of desired and interference symbol
candidates as the set of the desired and interference
signal symbols to be transmitted; and

d) outputting bit streams which correspond to said
determined set of the desired and interference signal
symbols.

21. The method of claim 20, wherein the step of generating
metric values further comprises the steps:

a)   providing transmission channel parameters both of the desired and interference signals;

b)   generating a replica signal of the respective received sub-carrier signal from said plurality of sets of desired and interference signal symbol candidates and said transmission channel parameters,

c)   calculating an estimation error signal from said received sub-carrier signal and said replica signal of said received sub-carrier signal;

d)   computing metric values from said estimation error signal;

e)   determining the most likely set of desired and interference symbol candidates as the set of desired and interference symbols to be transmitted by comparing a plurality of calculated metric values which correspond to each set of desired and interference signal symbol candidates;

f)   estimating and/or updating said transmission channel parameters both of desired and interference signal by using said determined set of desired and interference signal symbols and said estimation error signal.

22. The method of claim 21, wherein the step of generating a replica signal of the respective received sub-carrier signal further comprises the steps:

a)   providing transmission channel parameters of the desired signal and of the interference signals;

b)   generating a replica signal of the desired signal;

c)   generating a replica signal of each interference signal;

d)   combining said replica signal of said desired signal
      and said replica signal of each interference signal.

23. The method of the claim 20 or 22, wherein the step 20.a)
     further comprises the steps:
a)   storing pre-known bit sequences as training bit
      sequences, for the desired signal and for at least one
      interference signal;
b)   performing a training mode which comprises the
      steps:
      i)   generating said desired signal complex modulation
            symbols which correspond to the set of training
            sequences,
      ii)   generating said interference signals complex
            modulation symbols which correspond to the set of
            training sequences;
      iii) multiplying said desired signal complex
            modulation symbols with said desired signal
            transmission channel parameters to obtain a
            desired signal replica,
      iv)   multiplying said interference signal complex
            modulation symbols with the respective
            interference signal transmission channel
            parameters to obtain respective interference
            signal replicas;
      v)   combining said desired signal replica and said
            interference signal replicas to obtain a replica
            signal for each received sub-carrier signal;
      vi)   subtracting said replica signal of the respective
            received sub-carrier signal from the respective
            received sub-carrier signal to obtain an error
            signal; and

vii) recursively updating said desired and
interference signal transmission channel
parameters by using said error signal and said
desired and interference signal complex
modulation symbols and providing renewed desired
and interference signal transmission channel
parameters;

viii) recursively repeating the steps i) to vii) during
the training mode;

c)   performing a tracking and information decoding mode
which comprises the steps:

i)   sequentially generating a plurality of bit sets
of desired and interference signal candidates as
the basis of a maximum likelihood estimation;

ii) generating complex modulation symbols according
to a plurality of said sets of desired and
interference signals;

iii) multiplying said desired signal complex
modulation symbols by said desired signal
transmission channel paramters;

iv) multiplying said interference signal complex
modulation symbols with said interference signal
transmission channel paramters;

v)   combining the results of steps iii) and iv) to
form a replica of a respective received sub-
carrier signal;

vi) subtracting said replica of received signal from
the respective received sub-carrier signal to
form estimation error signals;

vii) computing absolute-squared values of said
estimation error signals as said metric values;

viii) determining the most likely bit set of desired
and interference signal candidates as the bit set
of desired and interference signal to be
transmitted by comparing a plurality of said
metric values on the basis of a maximum
likelihood estimation;

ix) generating the set of desired and interference
signal complex modulation symbols according to
said determined bit set of desired and
interference signal;

x) estimating and/ or recursively updating said
transmission channel parameters of desired and
interference signals by using said determined set
of desired and interference signal complex
modulation symbols and said estimation error
signal which corresponds to said determined set
of desired and interference signal complex
modulation symbols; and

xi) recursively repeating the steps i) to x) during
the information data decoding mode.

24. The method of claim 23, wherein step b) is replaced by
the following steps:

a) generating said desired signal complex modulation
symbols which correspond to the set of training
sequences;

b) generating said interference signals complex
modulation symbols which correspond to the set of
training sequences,

c) estimating desired and interference signal
transmission channel parameters by calculating cross-
correlation between the respective sub-carrier signal

and said complex modulation symbol sequences of said
desired and interference signals.

25. The method of anyone of the claims 19 to 24 comprising
the steps:
a)   receiving said serial baseband multi-carrier signal
      over a plurality of diversity receiving branches;
b)   converting each serial baseband multi-carrier signal
      into a plurality of baseband sub-carrier signals;
c)   diversity combining respective sub-carrier signals
      of each diversity receiving branches and canceling of
      co-channel interference in the diversity combined sub-
      carrier-signals.

26. The method of claim 25, wherein step 20.b) comprises the
steps:
seperately generating metric values from each respective
received sub-carrier signal to be diversity combined and
said plurality of sets of desired and interference signal
symbol candidates and
diversity combining the seperately generated metric
values.
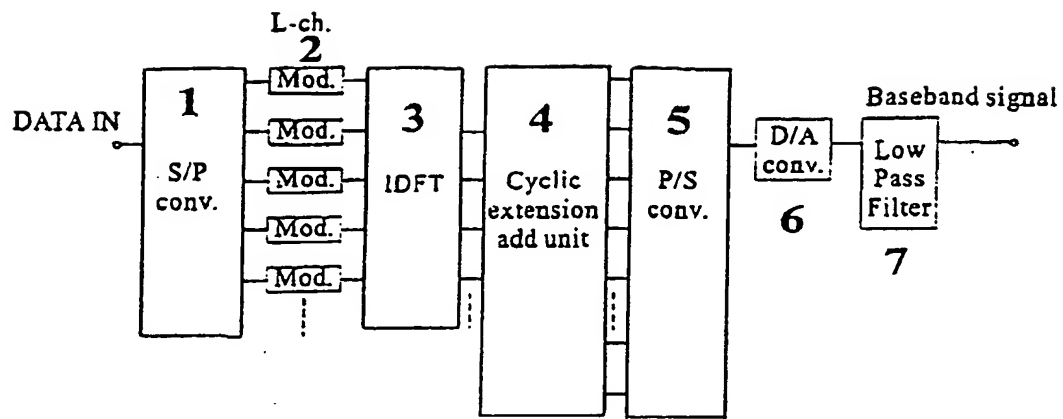
Fig.1A
PRIOR ART

Fig. 1B
PRIOR ART

0 Multi-carrier/ OFDM
Demodulator

12   **13**

Baseband
signal

10   **11**   S/P conv.   Remove cyclic extension   **14**   **17**   **16**

Lowpass filter   A/D conv.   DFT   Interference Canceller and Signal Detector Part (IC)   P/S conv.

FIG. 2A

17

IC **17₁**

IC **17₂**

IC **17ₗ**

IC **17L**
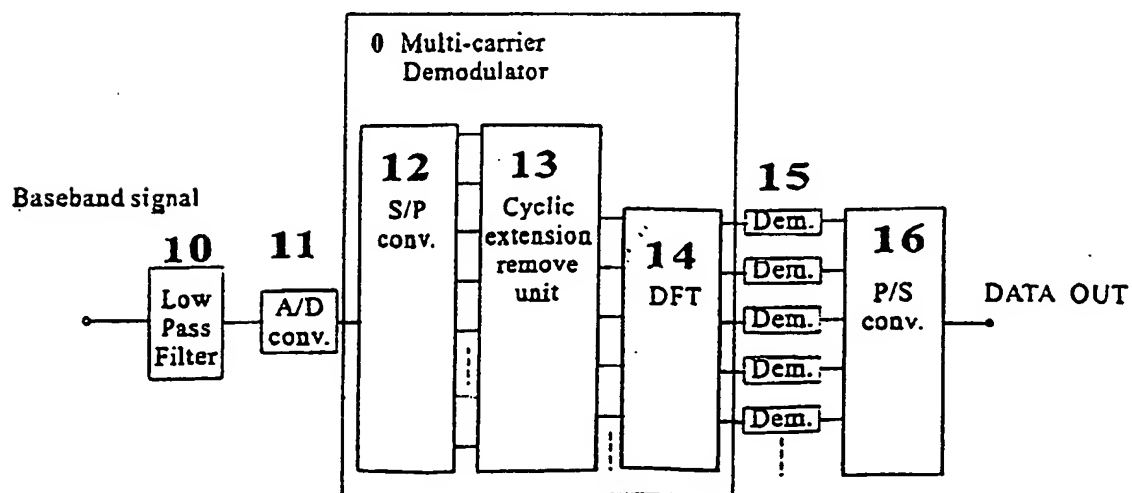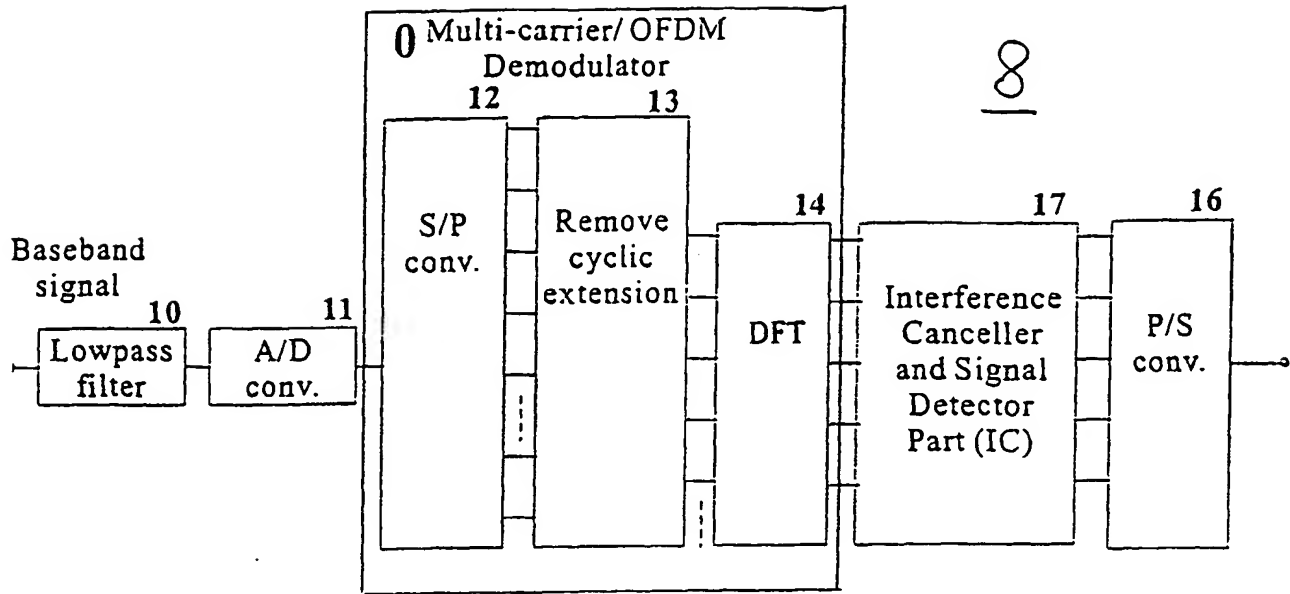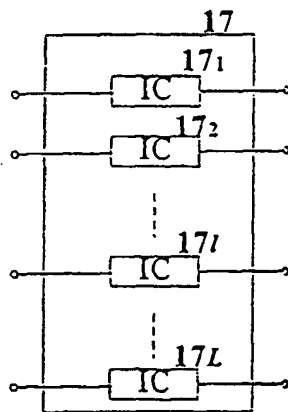
FIG. 2B

17l Interference Canceler for the *l*-th sub-carrier

18

Symbol candidate (desired signal)

Symbol candidate
(interference signal # l)

Metric Generator

Symbol candidate
(interference signal #N)

40

$y_l(n)$

IN   Transmitted Symbol Estimation part   OUTd
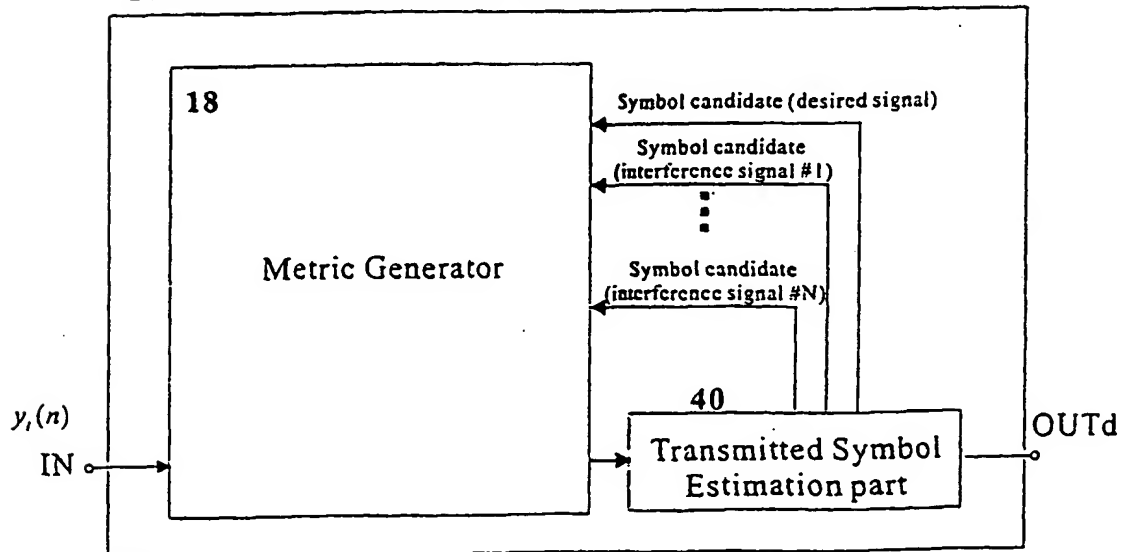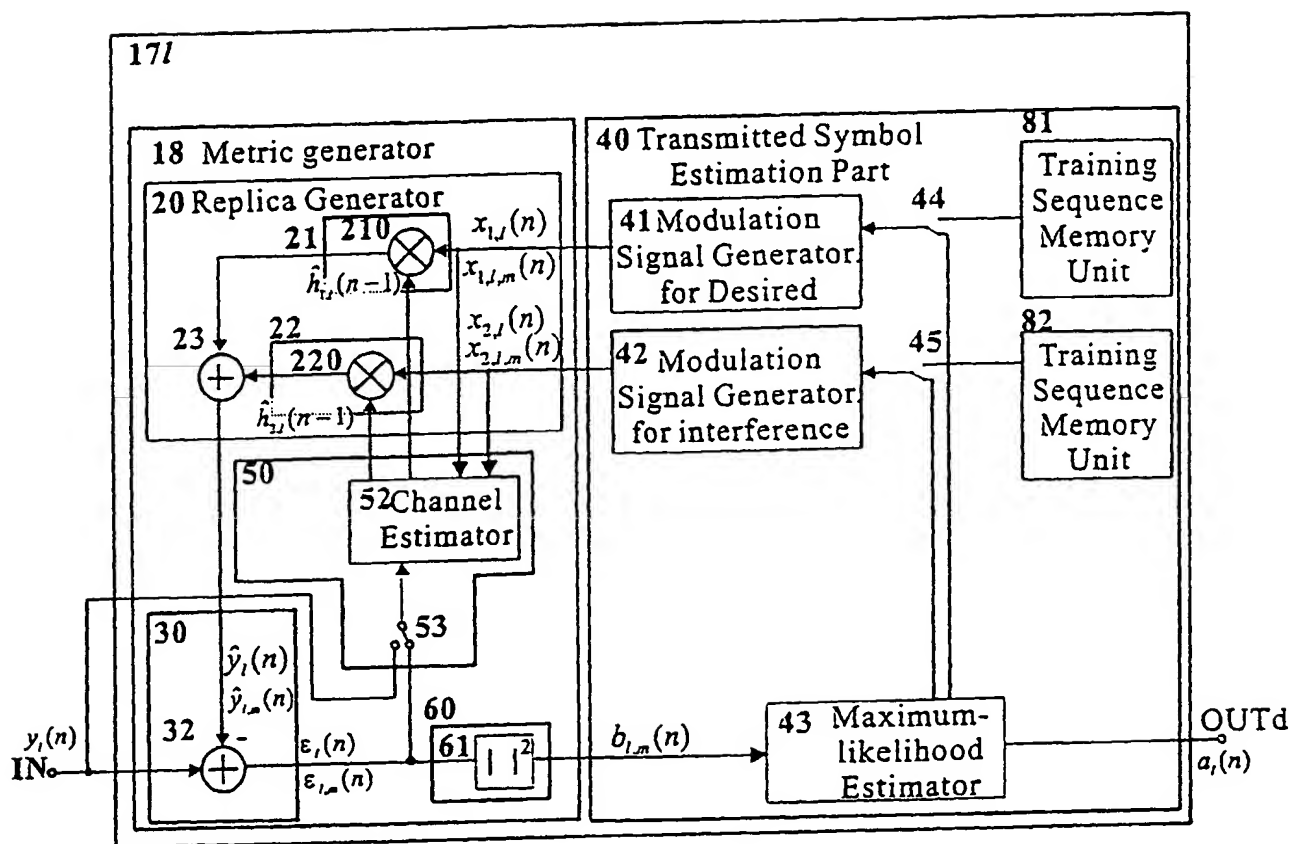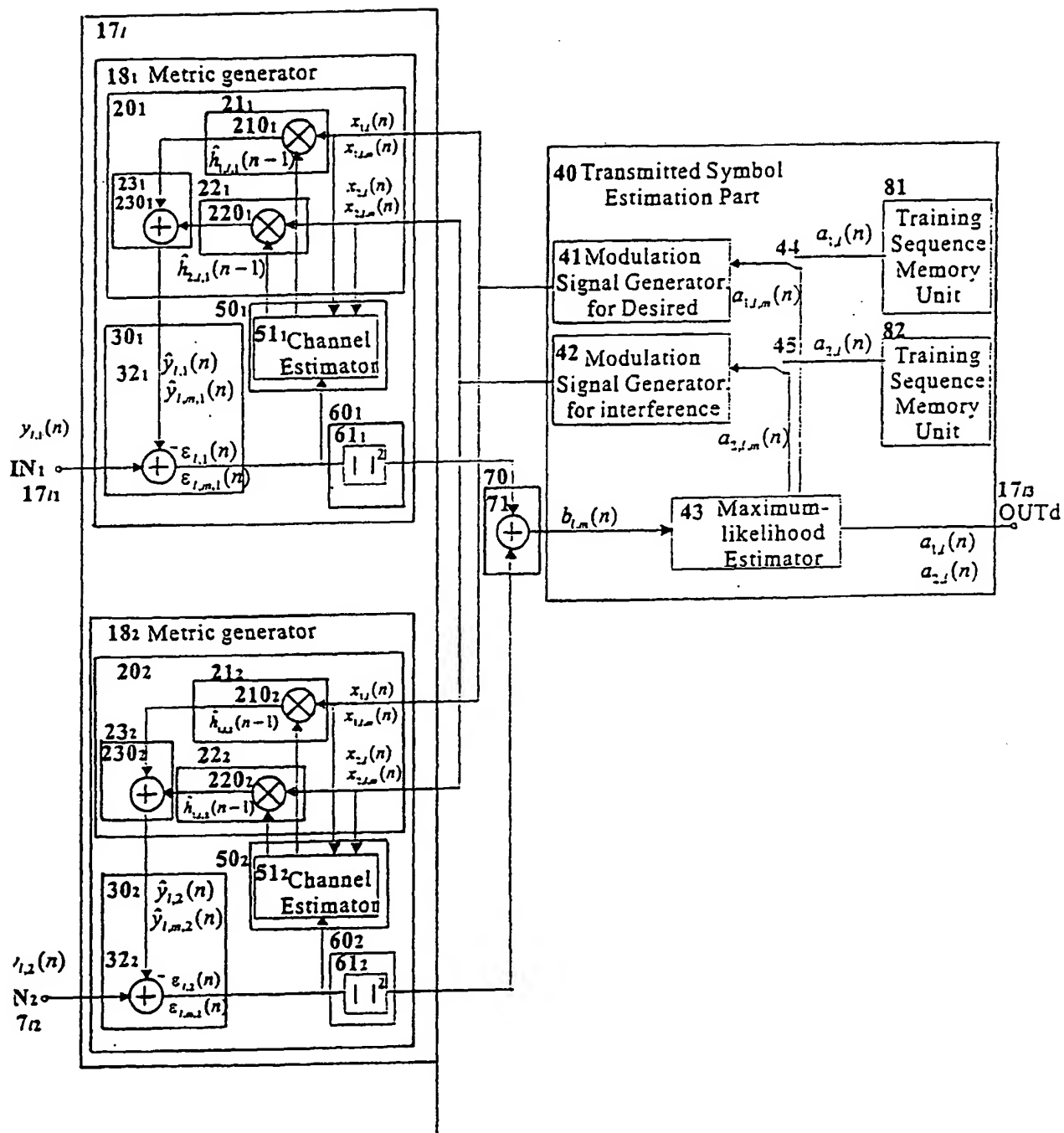
FIG. 2C
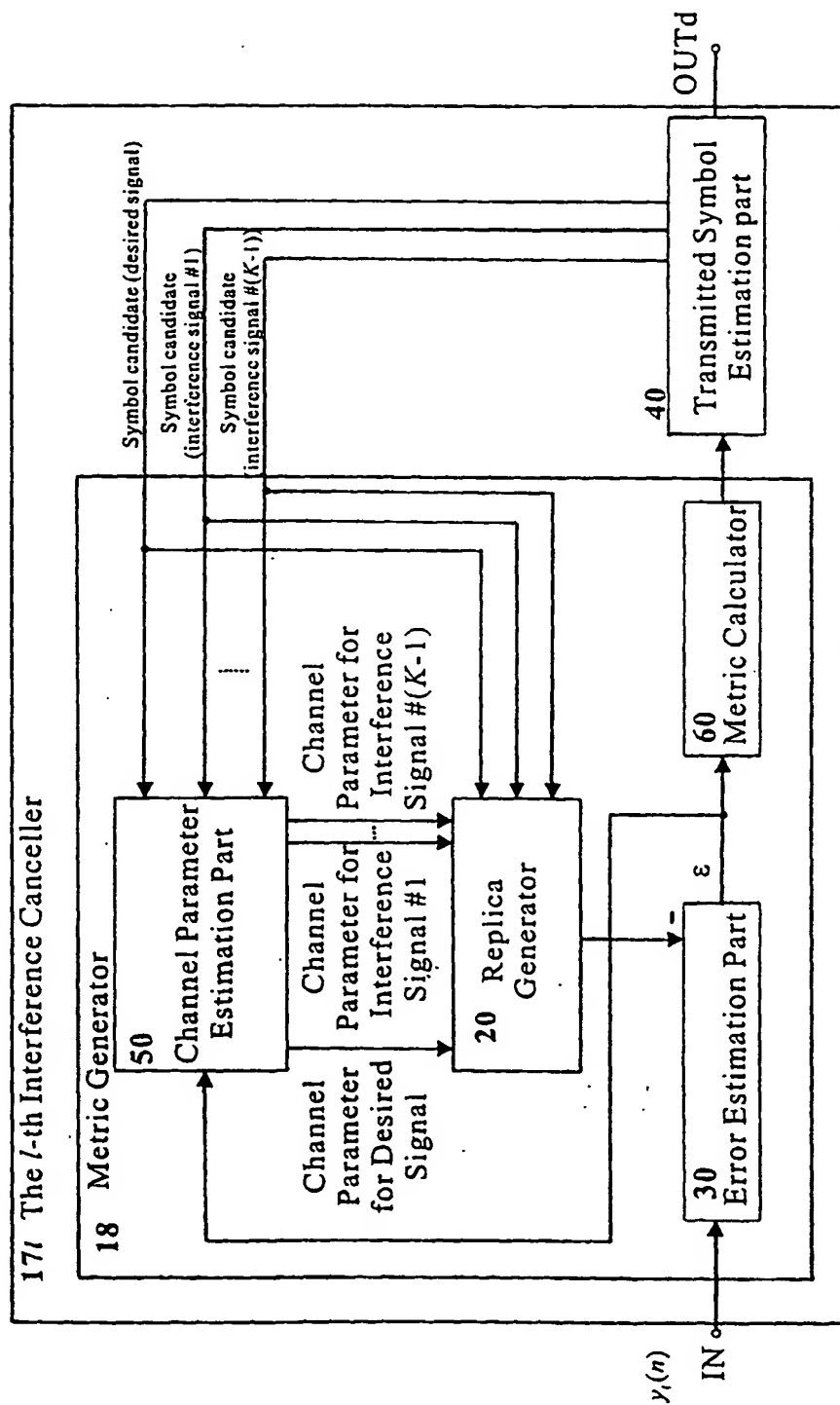
FIG. 3
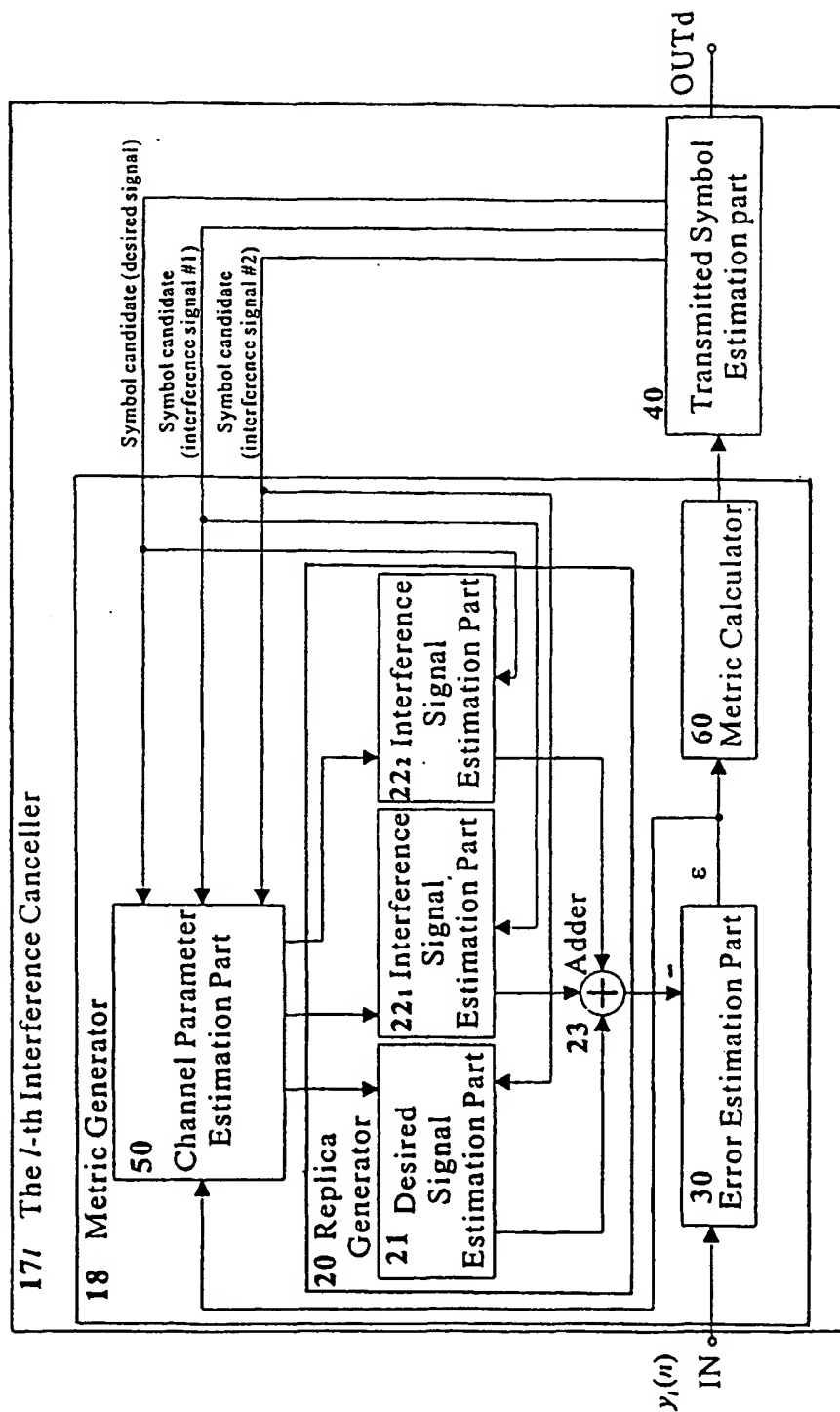
FIG. 4
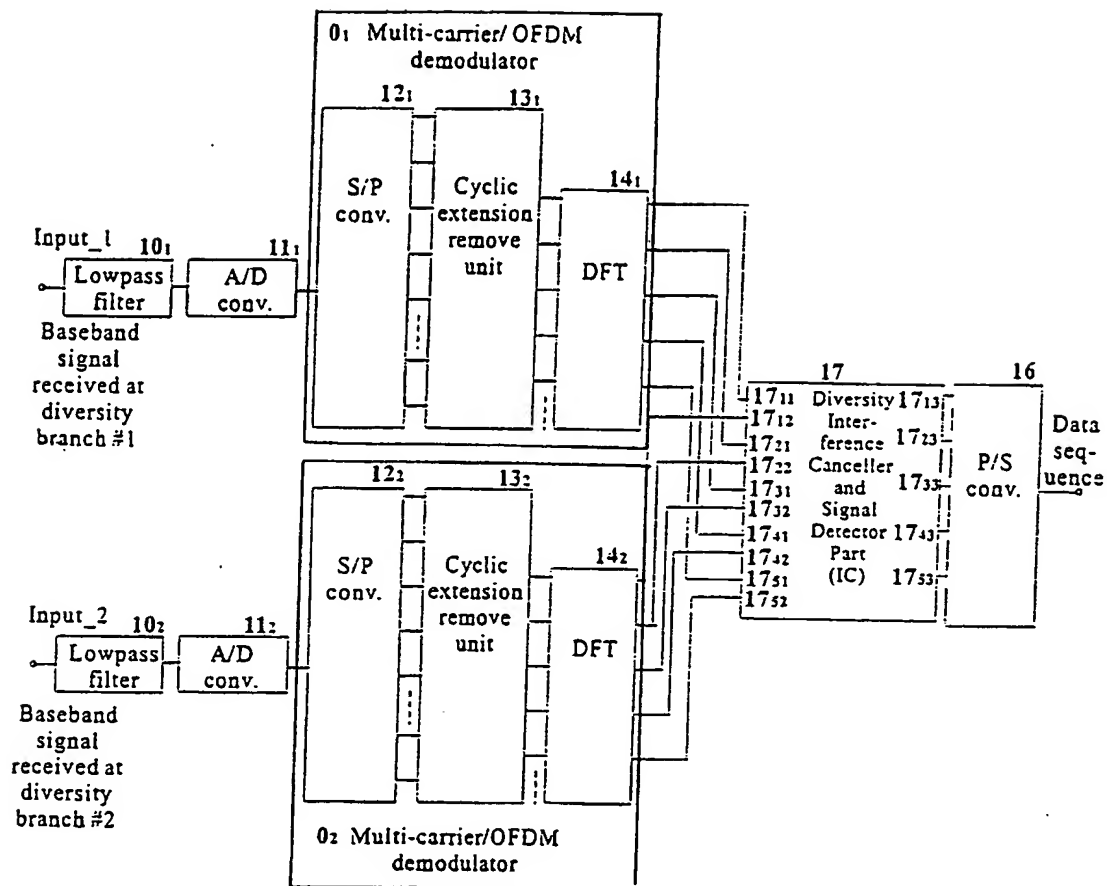
FIG. 5A
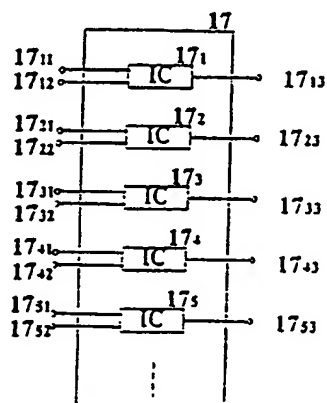
FIG. 5B
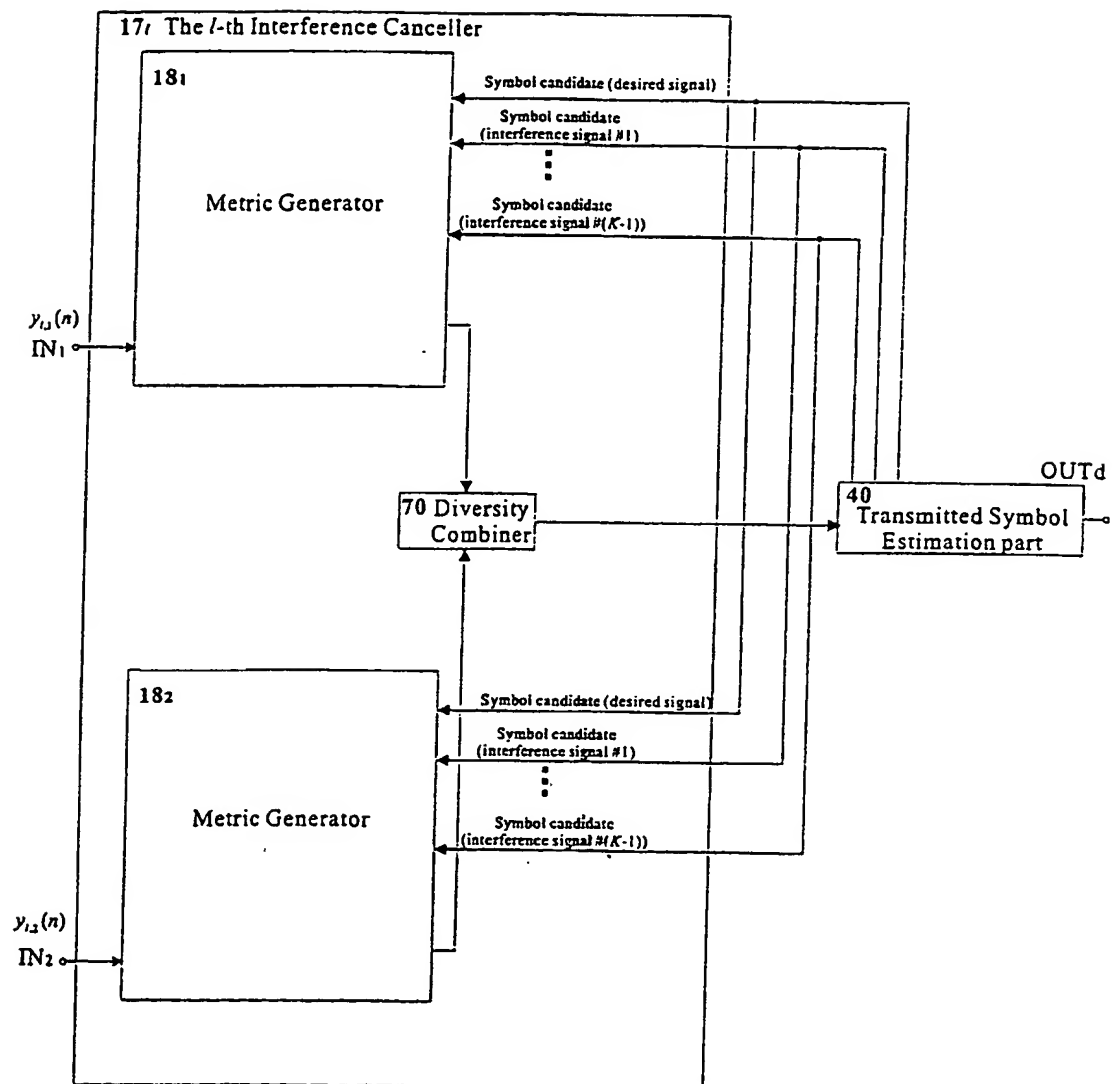
FIG. 5C
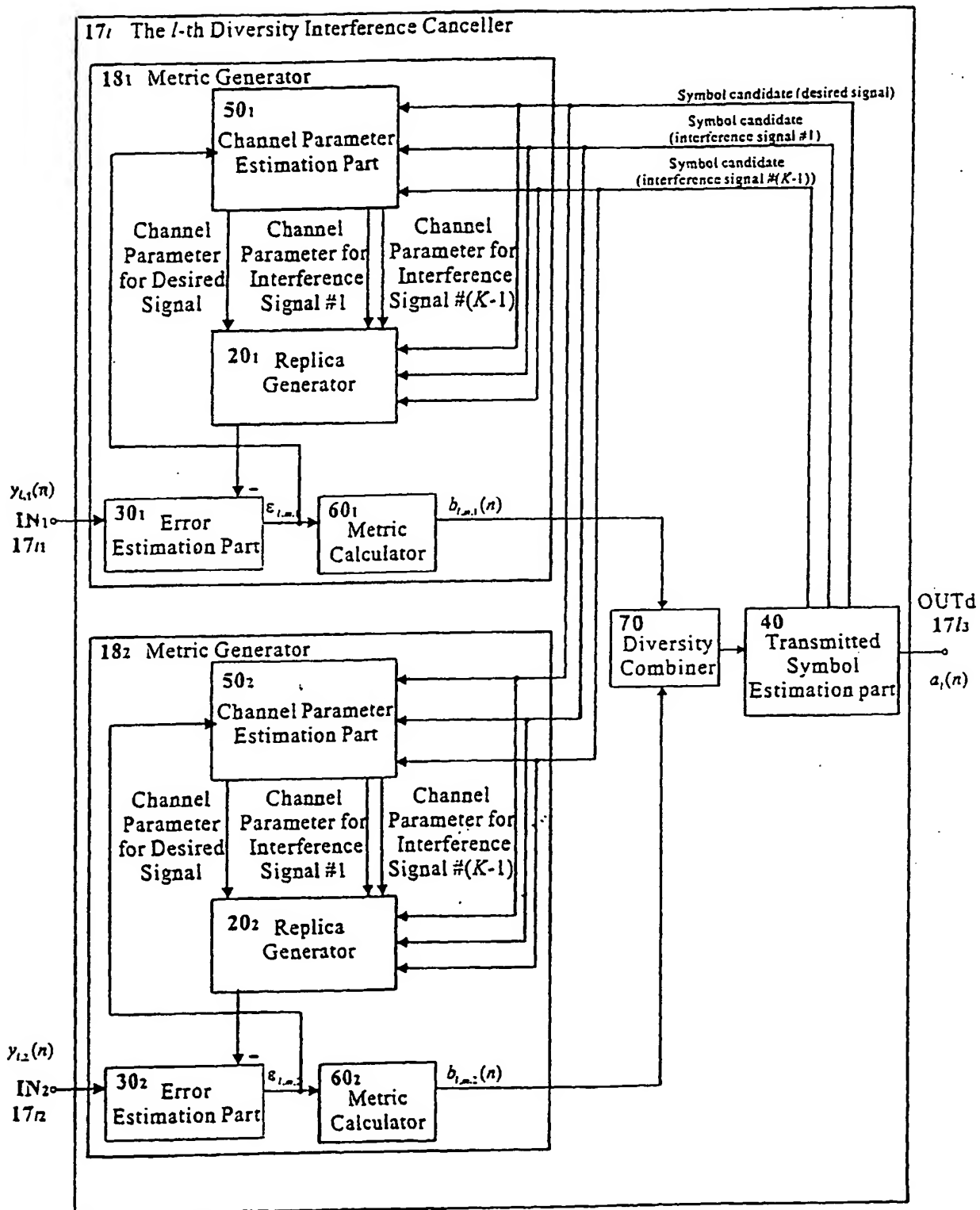
FIG. 6
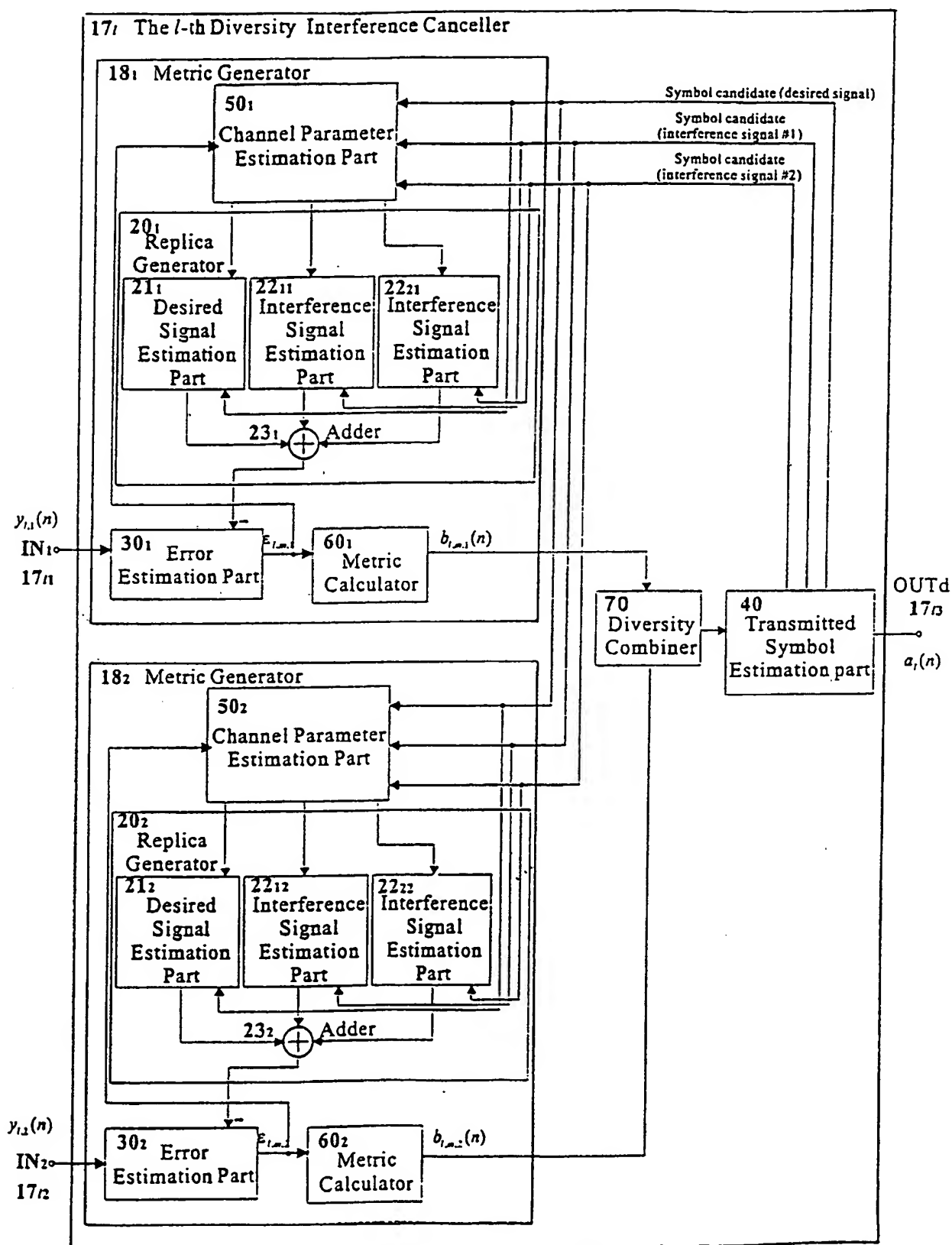
FIG. 7
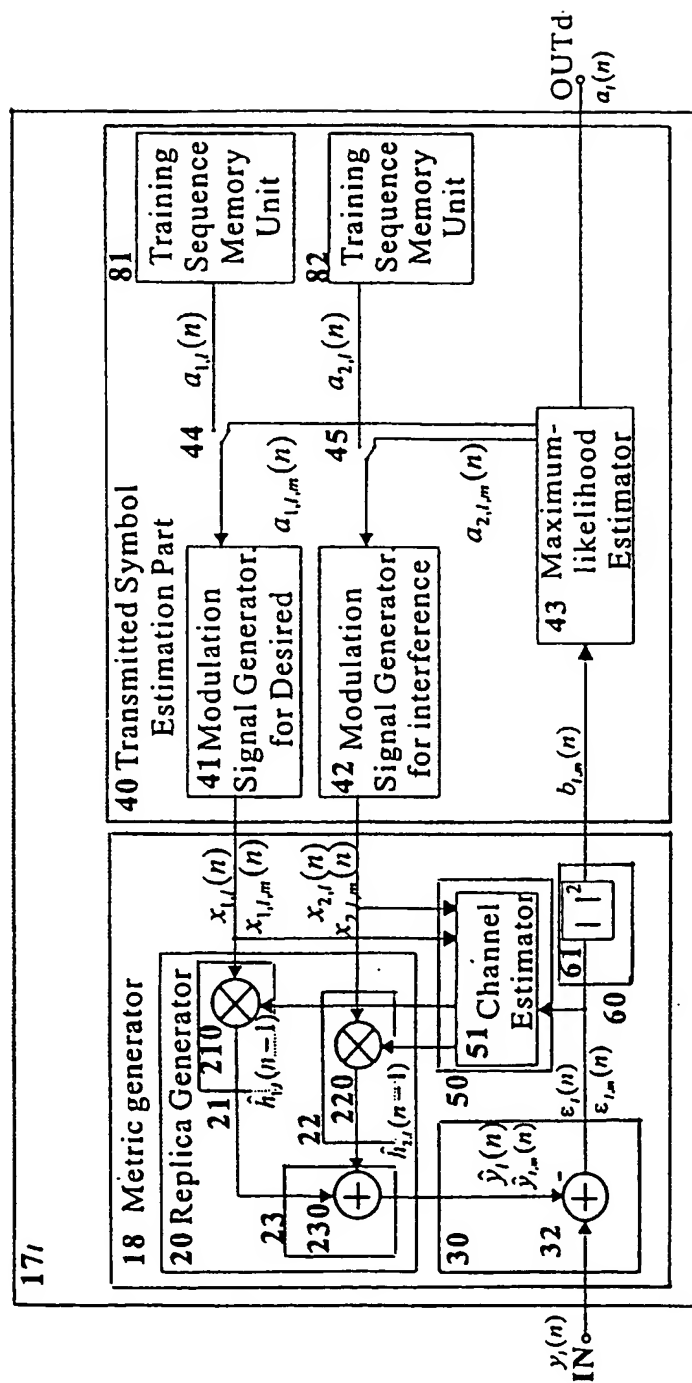
FIG. 8

FIG. 9

FIG. 10

FIG. 11

FIG. 12

FIG. 13

A single path Rayleigh
fD = 52 Hz
Avg. Eb/N0 = 30 dB
w/ a single CCI signal.
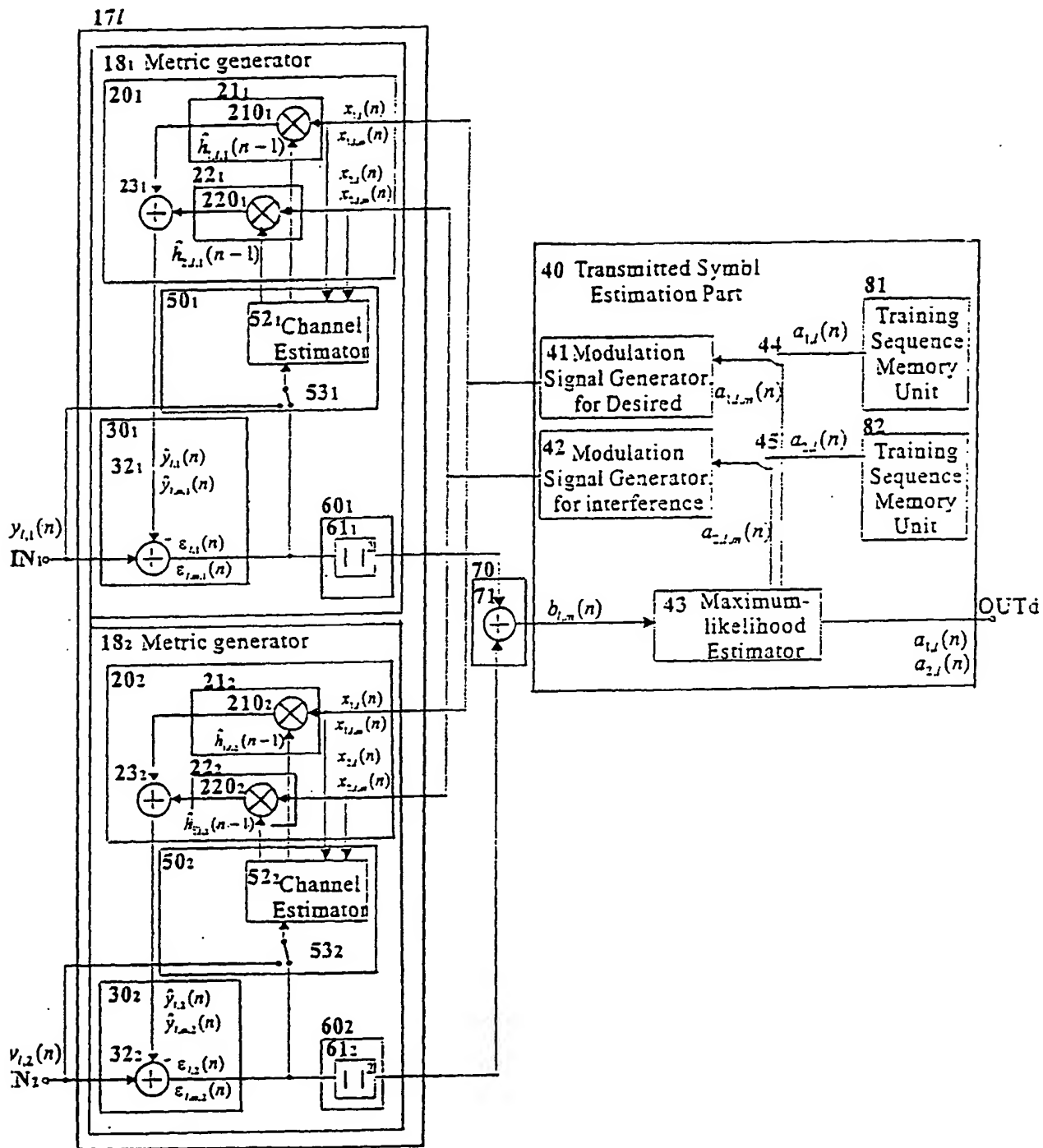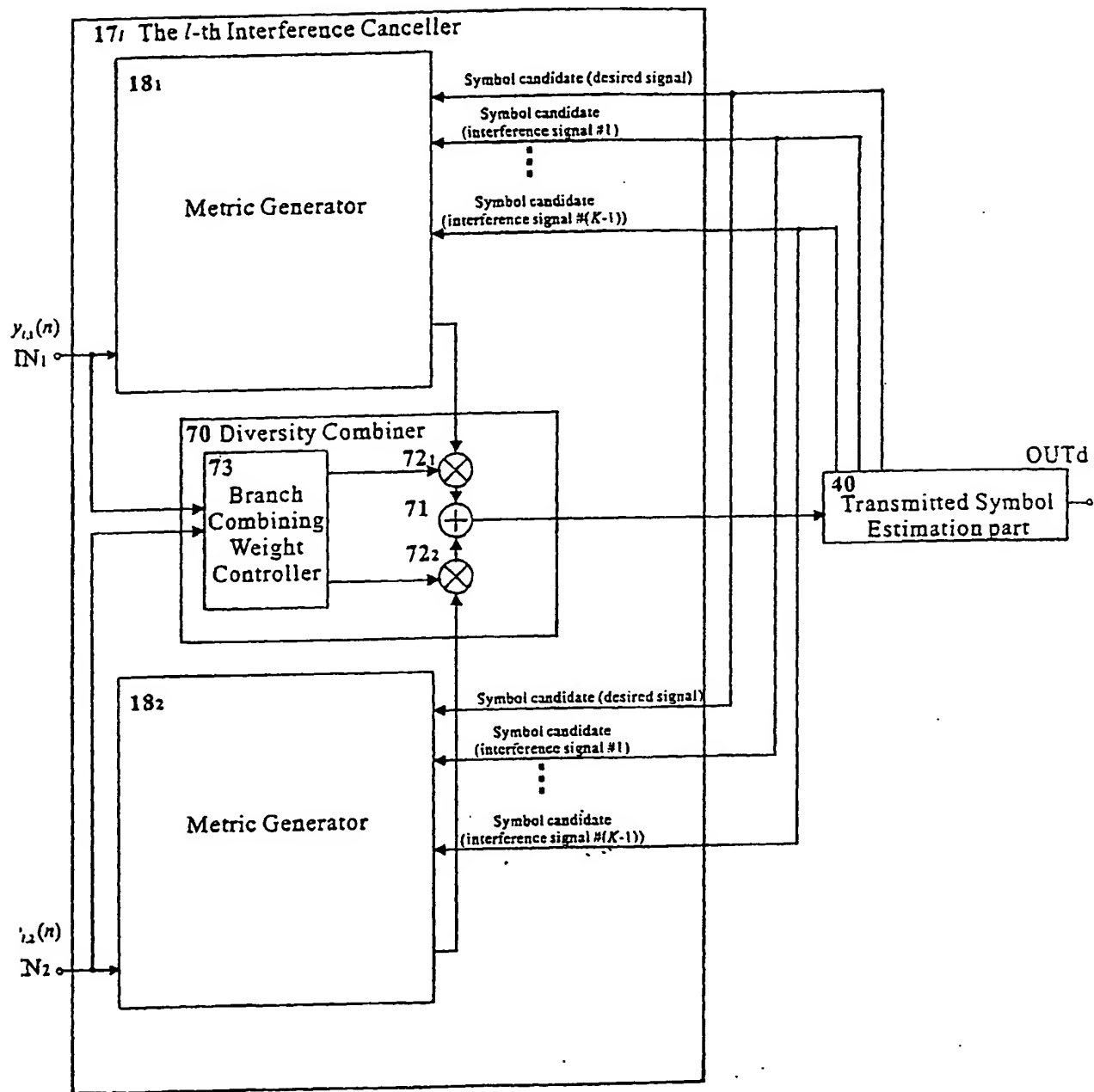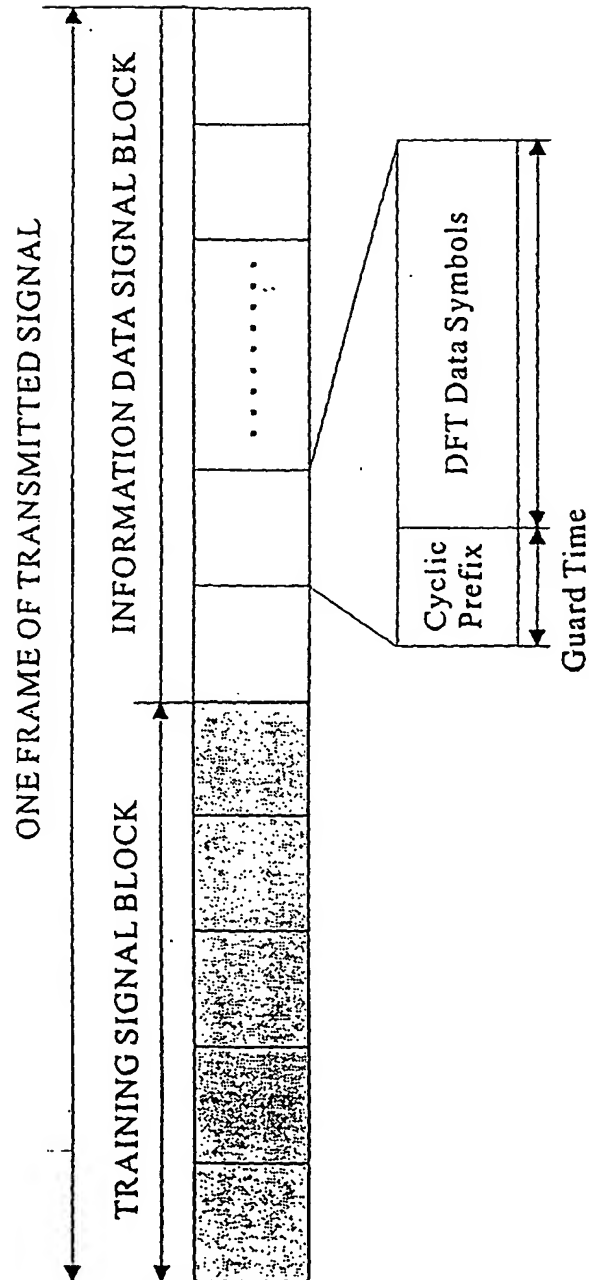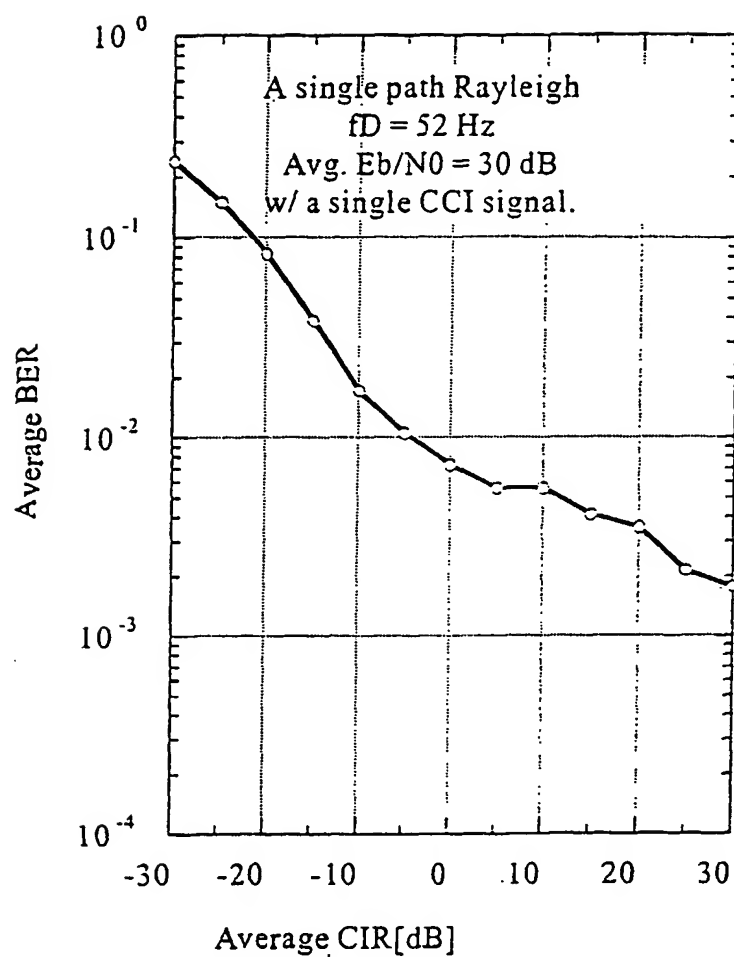
FIG. 14

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04L27/26   H04L25/03   H04B7/08   H04L1/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04L   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 867 478 A (BAUM KEVIN LYNN ET AL) 2 February 1999 (1999-02-02) column 1, line 21 - line 41 column 3, line 15 - line 26 column 4, line 13 -column 5, line 59 column 12, line 15 -column 13, line 6 column 15, line 1 - line 65 column 17, line 8 - line 23 column 18, line 1 - line 8 column 23, line 64 -column 27, line 41; figures 15-19 column 28, line 21 - line 37; figure 22 ---/---	1-26

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 July 2000	09/08/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Koukourlis, S

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 537 443 A (YOSHINO HITOSHI ET AL) 16 July 1996 (1996-07-16) cited in the application abstract column 7, line 9 - line 40 column 9, line 29 -column 10, line 62 column 22, line 32 -column 25, line 32 figures 3,4,15 claims	1-26
A	US 5 973 642 A (SOLLENBERGER NELSON RAY ET AL) 26 October 1999 (1999-10-26) claims	1-26
A	MUNSTER M ET AL: "Co-channel interference suppression assisted adaptive OFDM in interference limited environments" IEEE VTS 50TH VEHICULAR TECHNOLOGY CONFERENCE, 19 - 22 September 1999, pages 284-288 vol.1, XP002143788 Piscataway, NJ, USA ISBN: 0-7803-5435-4 the whole document	1-26

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5867478	A	02-02-1999	EP 0983654 A WO 9859450 A		08-03-2000 30-12-1998
US 5537443	A	16-07-1996	EP 0637139 A WO 9417600 A JP 2678823 B		01-02-1995 04-08-1994 19-11-1997
US 5973642	A	26-10-1999	NONE		